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SAIL-thermique, a model to simulate land surface emissivity (LSE) spectra

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IRD, UMR LISAH, Montpellier, France



Introduction

- ❑ Land Surface Emissivity (LSE) is required for deriving Land Surface Temperature (LST)

- ❑ Emissivity spectra are required for:
 - interpreting atmospheric sounding from hyperspectral TIR sensors (AIRS, IASI)
 - analyzing relation with surface and vegetation moisture, plant chemistry (?)
 - species identification (?) -> specific spectral features

- ❑ There is very few available information on LSE and spectral LSE
except from multispectral TIR sensors as ASTER and few leaf samples in spectral libraries
(measurements are complex and up to recently only geologists were interested)

- ❑ Few models of LSE accounting for vegetation canopy characteristics exist
(eg. Anton and Ross 1990, Olioso 1992, Snyder and Wan, 1998, 4SAIL Verhoef et al. 2007...)

- ❑ None (?) of them was evaluated against data

Recent progress

❑ Hyperspectral and multispectral sensors

- ASTER, MODIS,...
 - IASI, AIRS...
- } ⇒ Spectral LSE maps, better than older climatologies (?)
- future missions : HysPIRI, ECOSTRESS, IASI-2, TRISHNA... => better accuracy is expected

❑ Spectral libraries

- ASTER and MODIS spectral libraries provided first information
 - ⇒ almost all LSE and LST extraction algorithms
- new information on
 - ⇒ spectra for leaf of various plant species
 - ⇒ emissivity spectra changes with moisture level (leaf and soil)
 - ⇒ leaf spectra model in 0.4 - 5.7 μm range (PROSPECT-VISIR, Gerber et al. 2012)

❑ LSE models

- coherent results between different LSE models

But still no evaluation against data and not used for extracting LSE or build LSE maps

Hypothesis

- ❑ It is possible to use “standard” Radiative Transfer models for simulating land surface emissivity in presence of vegetation canopy

But

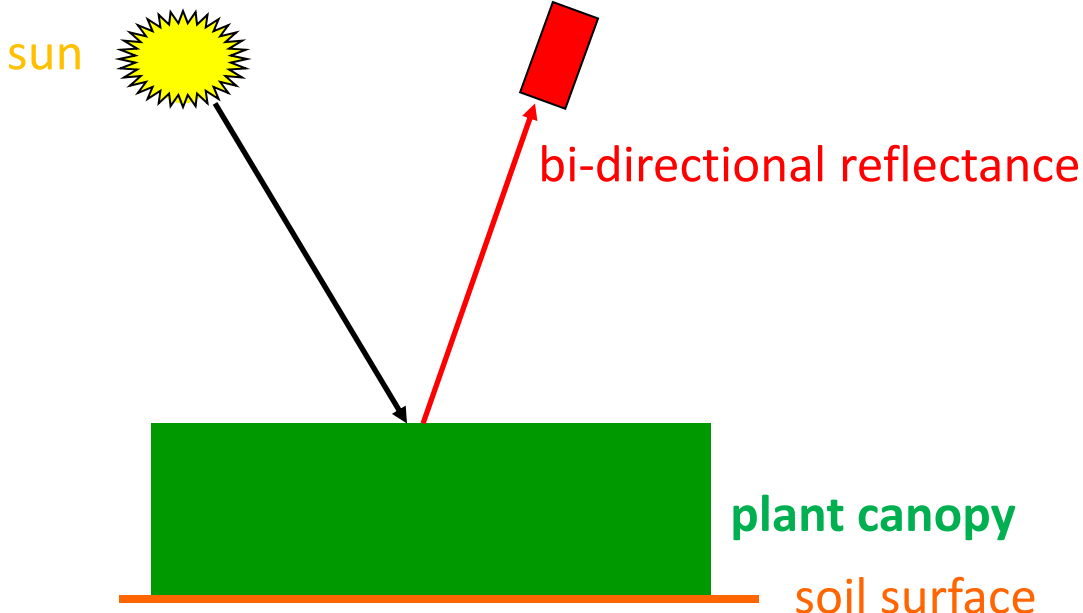
- ❑ Previous model evaluation were only done by comparison to other models
(ex: François et al., 1997, Guillevic et al., 2003, Sobrino et al., 2005, Ren et al. 2015...)
- ❑ We have to evaluate modeled land surface emissivity against in-situ measurements

In this talk:

- Presentation of the SAIL-Thermique land surface emissivity model
- Test of the model against ground data
- One example of application of the model for the (re-)evaluation of the Temperature-Emissivity-Separation algorithm (TES)

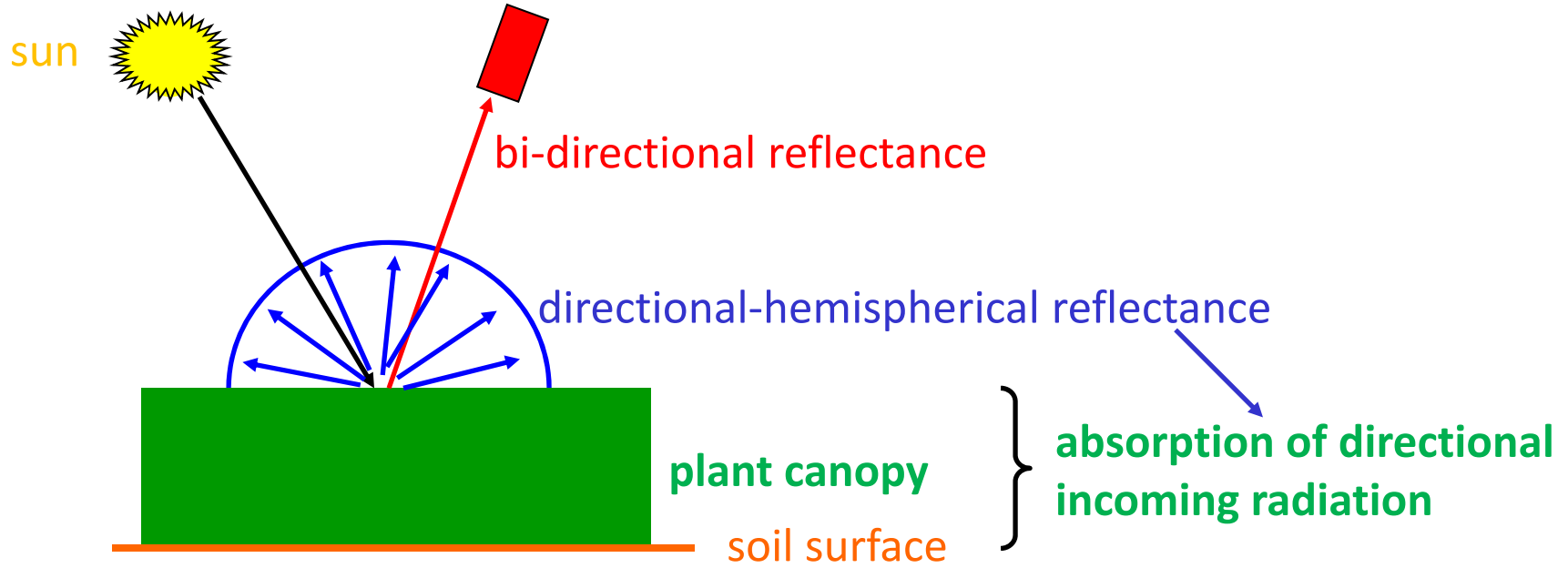
SAIL model

(Verhoef 1984-1985)

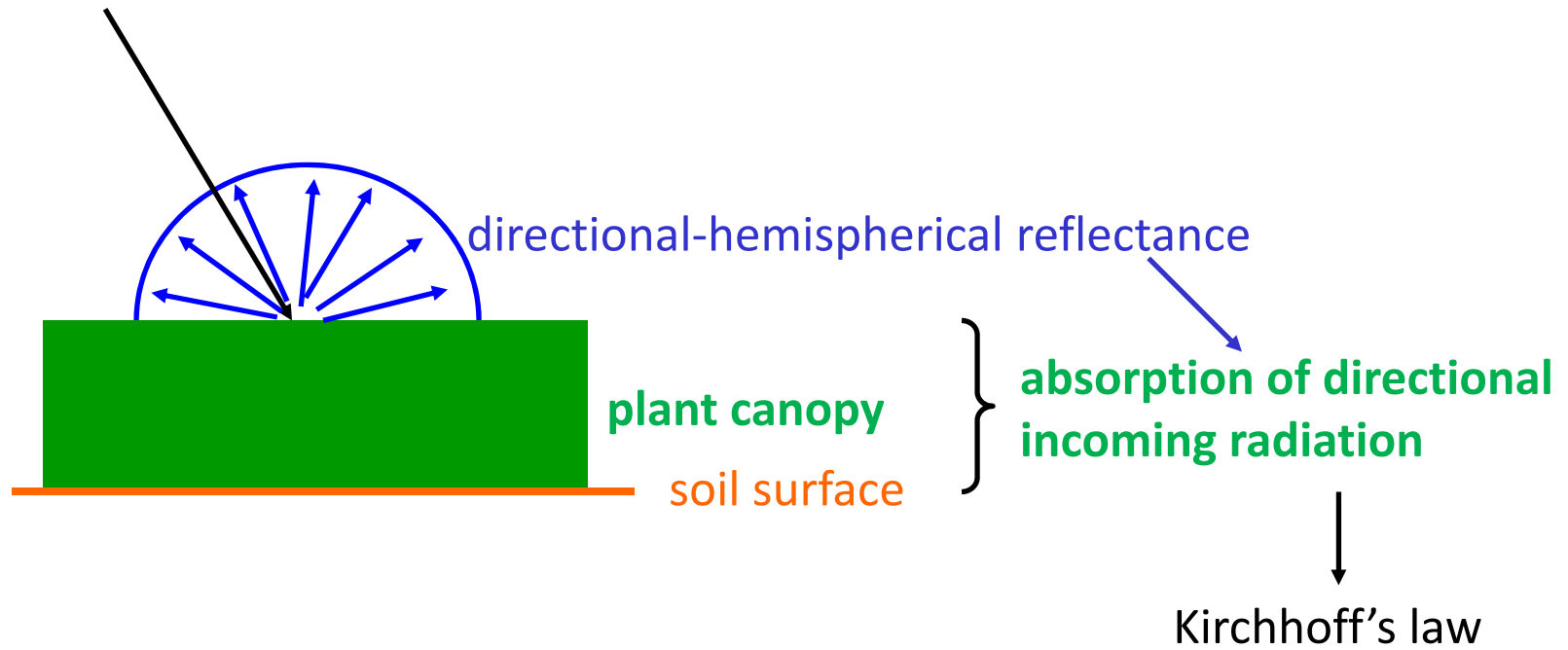


SAIL model

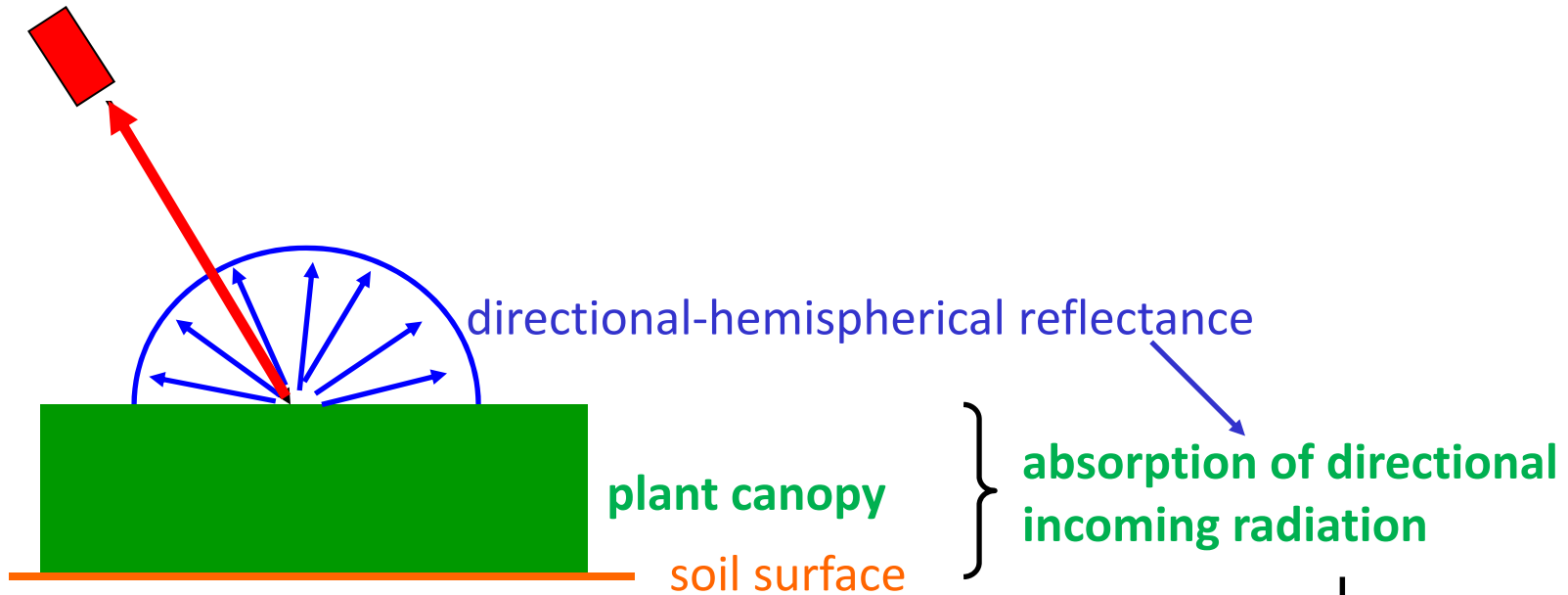
(Verhoef 1984-1985)



SAIL model (Verhoef 1984-1985)



SAIL model (Verhoef 1984-1985)



SAIL-Thermique model

Kirchhoff's law
↓
directional emissivity

Inputs and outputs of the SAIL and the SAIL-Thermique models

	SAIL	SAIL-Thermique
Inputs	<ul style="list-style-type: none"> • LAI • mean leaf angle • leaf/stem reflectances • leaf transmittance • soil reflectance • geometry of observation • Sun position 	<ul style="list-style-type: none"> • LAI • mean leaf angle • leaf/stem reflectances • leaf transmittance • soil reflectance • geometry of observation
Outputs	<ul style="list-style-type: none"> • spectral reflectances • NDVI • absorption of solar radiation (and albedo) 	<ul style="list-style-type: none"> • land surface emissivity • absorption of thermal radiation by vegetation and soil

One (strong) hypothesis: horizontally homogeneous canopy

but {

- several superposed horizontal layers
- several vegetation elements can be mixed

Test of the model: datasets -> LSE data

- ❑ Bibliographic data:

van de Griend and Owe (1993), Valor and Caselles (1996), Sugita et al. (1996)

- ❑ Available database including **ground measurements of land surface emissivity** :

DAISEX, Alpilles-ReSEDA, WATERMED

- ❑ Original data in Avignon and Camargue (HyEurope 2007)

- ❑ Most measurements done using the box method (few by using 'TES')

} → 8-14 or 8-13 μm
→ 1, 4 or 6 bands

-> overall: ~100 individual data points !!

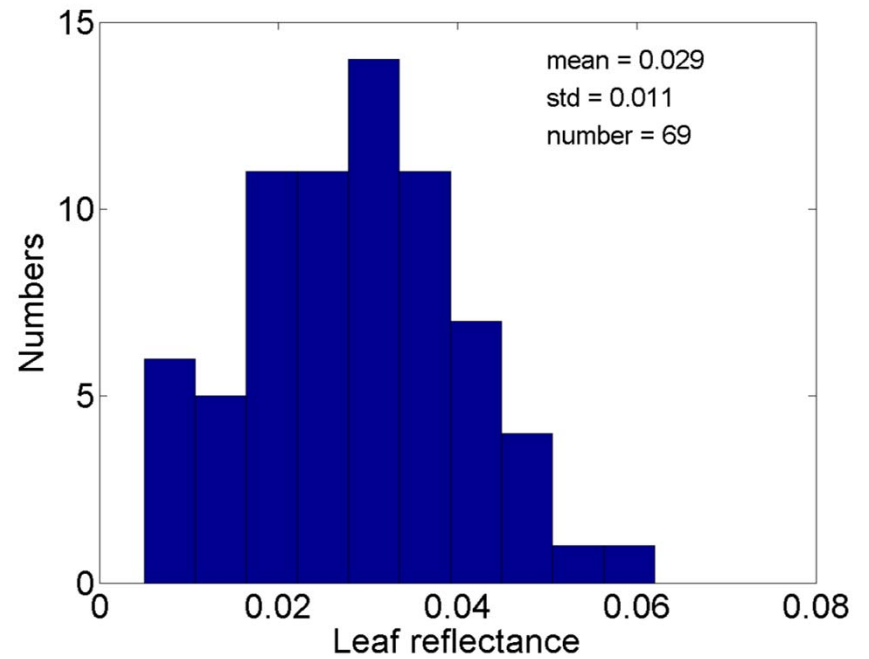
- ❑ Comparison to LES simulated using 4SAIL (Verhoef et al. 2007)

Test of the model: datasets

→ leaf reflectance : normal distribution with
[mean 0.029 and std 0.011]

leaf optical property data:

- ASTER spectral library
- MODIS spectral library
- Fuchs and Tanner 1966
- Idso et al. 1969
- Wang et al. 1994
- Coll et al. 2001

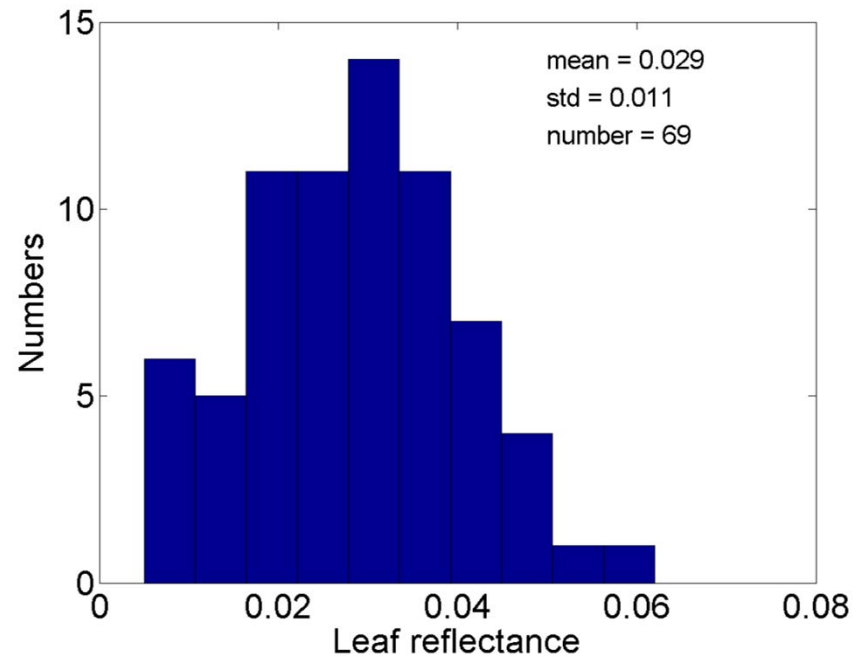


Test of the model: datasets

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[mean 0.029 and std 0.011]

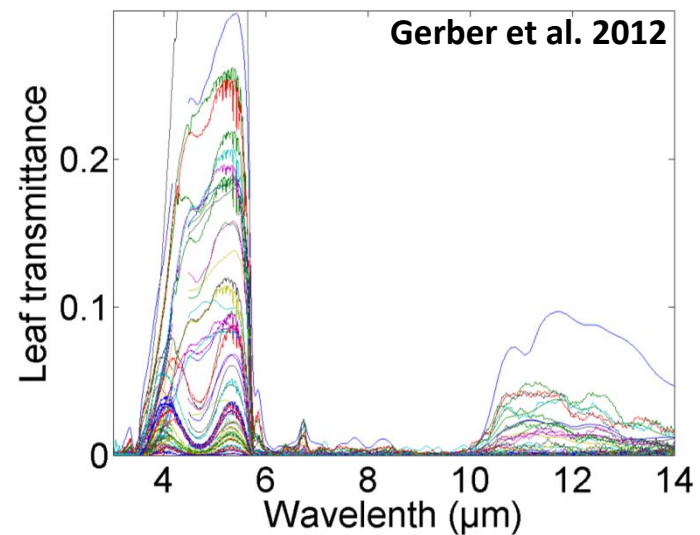
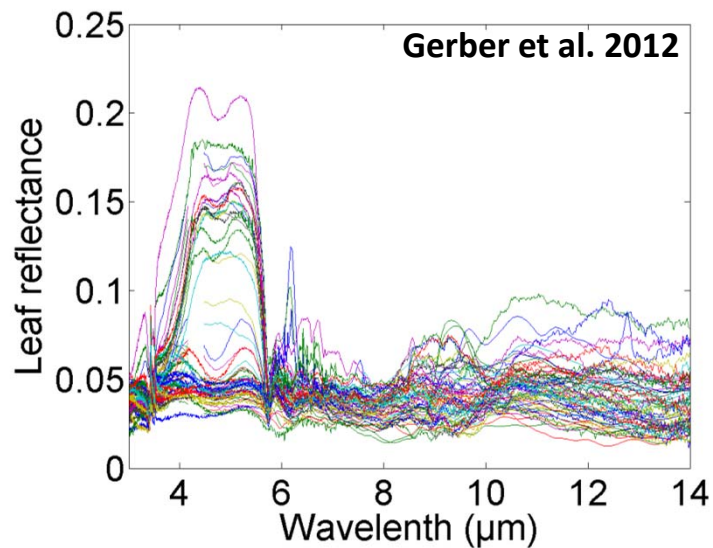
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- MODIS spectral library
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- Idso et al. 1969
- Wang et al. 1994
- Coll et al. 2001



new leaf optical property data:

- Gerber et al. 2012
- Fabre et al. 2012

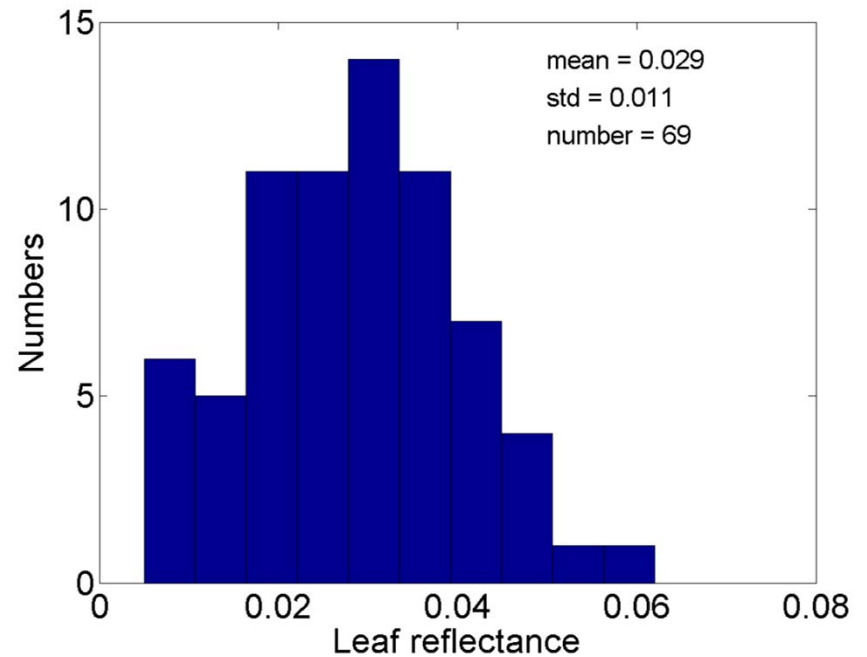


Test of the model: datasets

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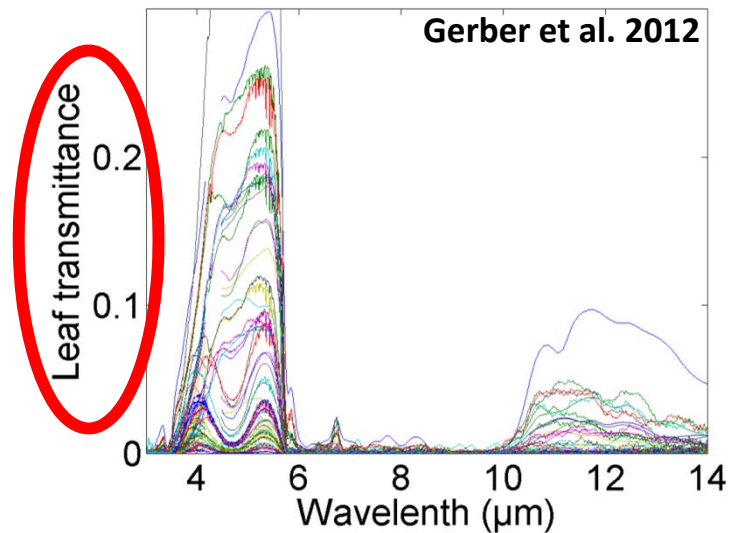
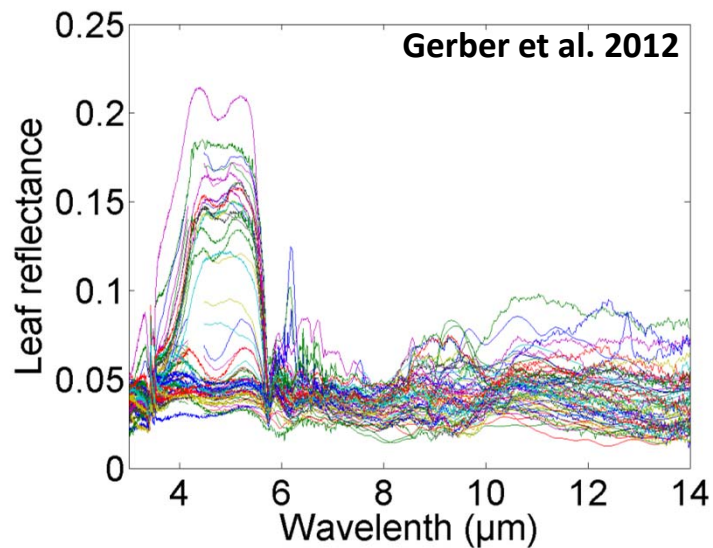
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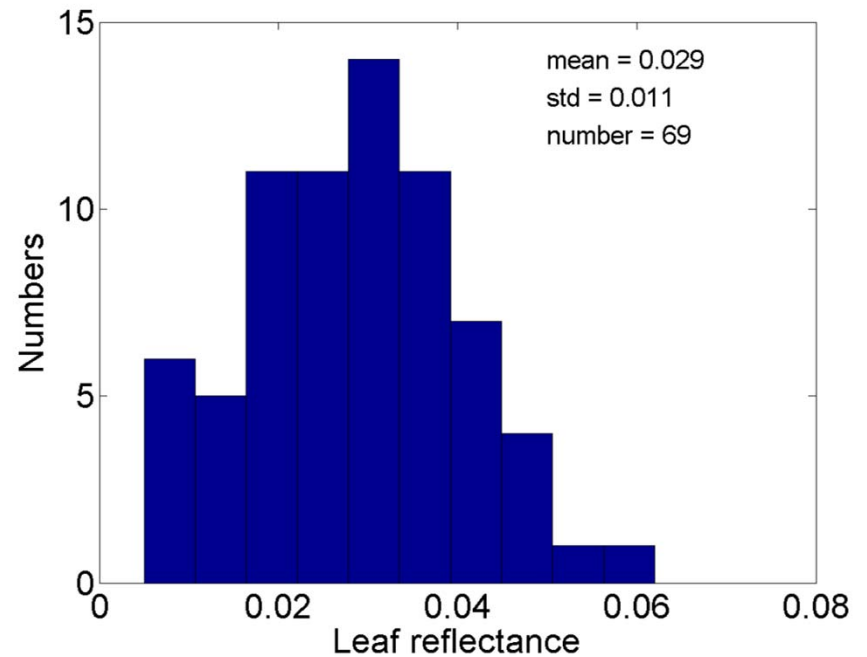


Test of the model: datasets

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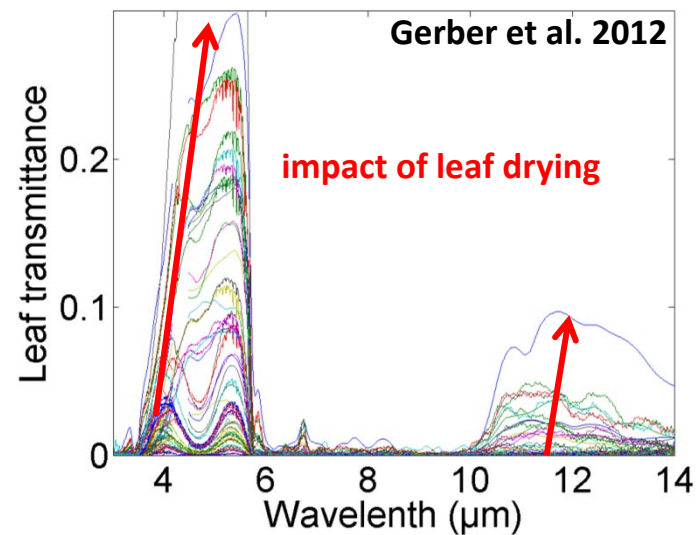
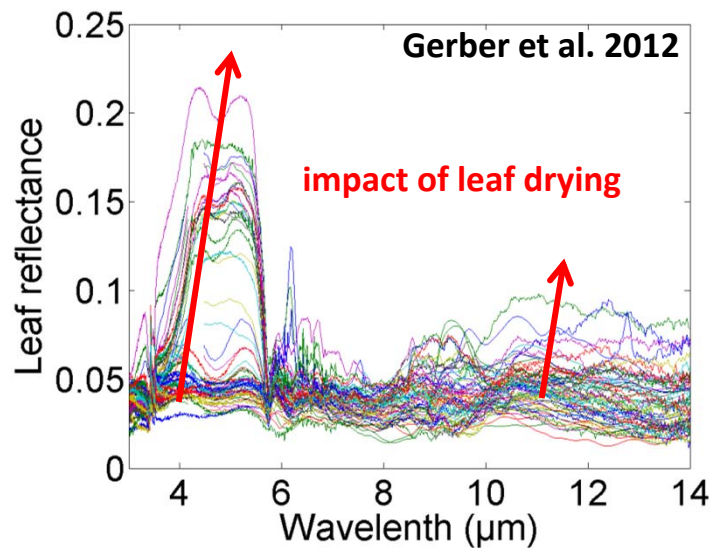
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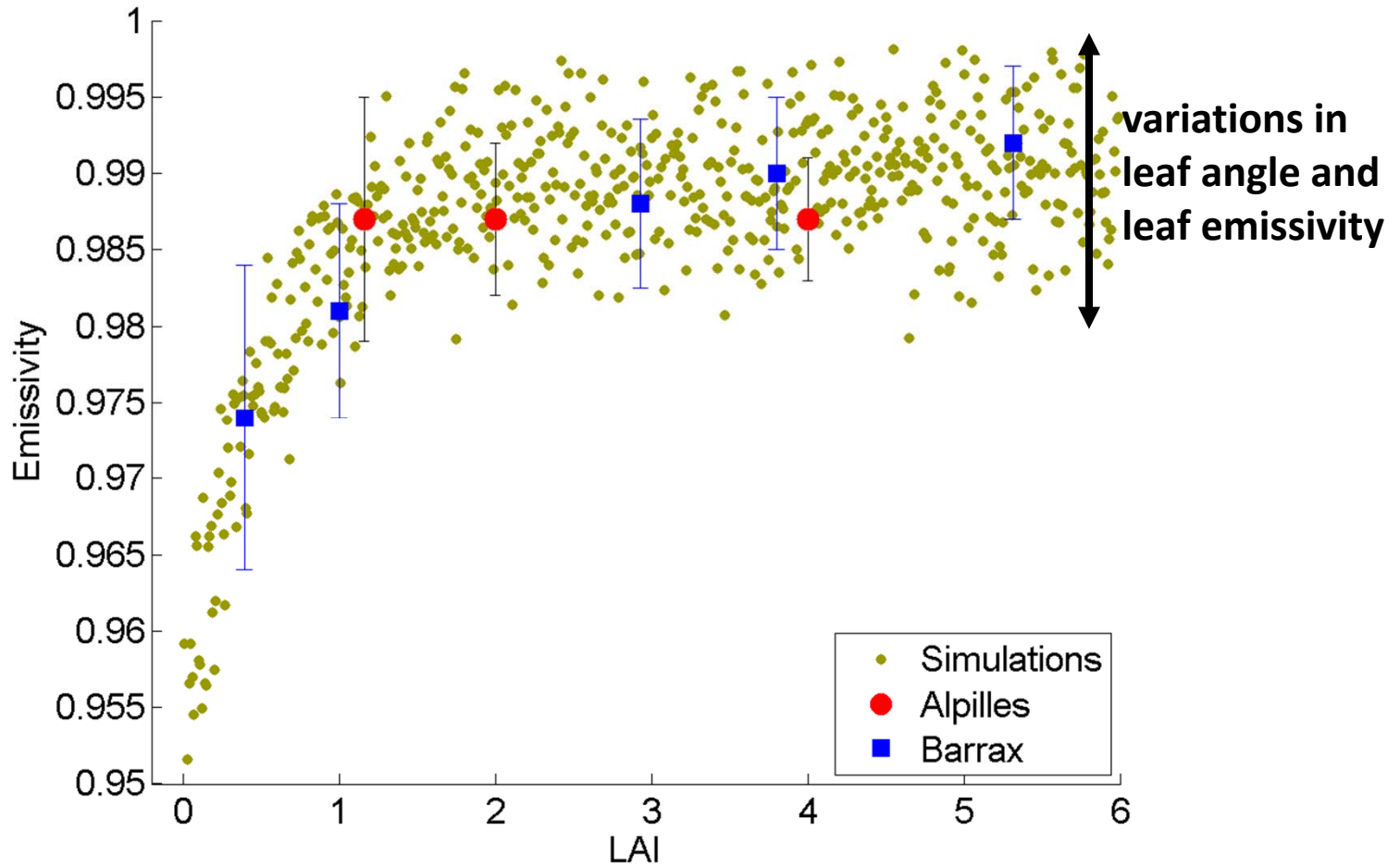


new leaf optical property data:

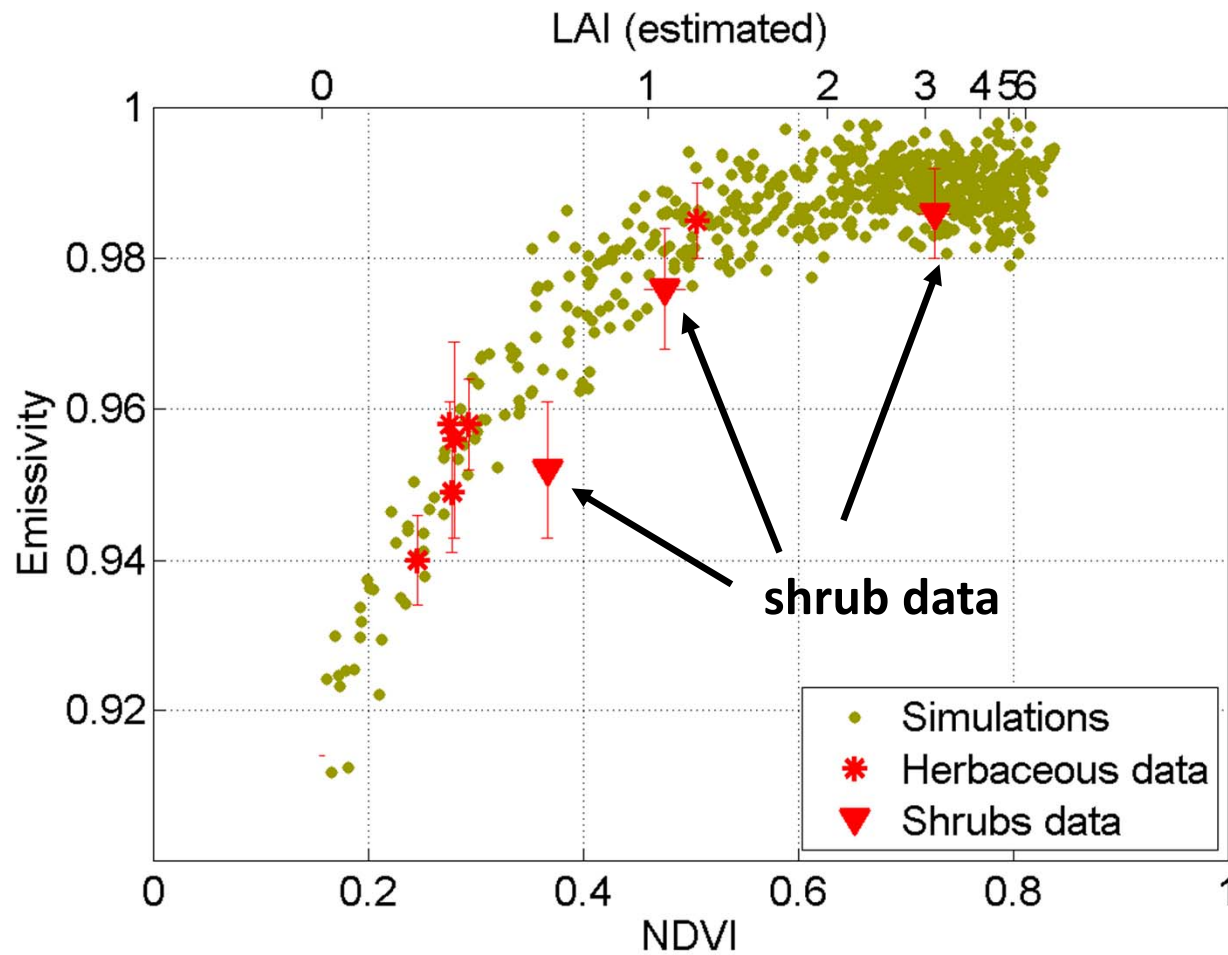
- Gerber et al. 2012
- Fabre et al. 2012



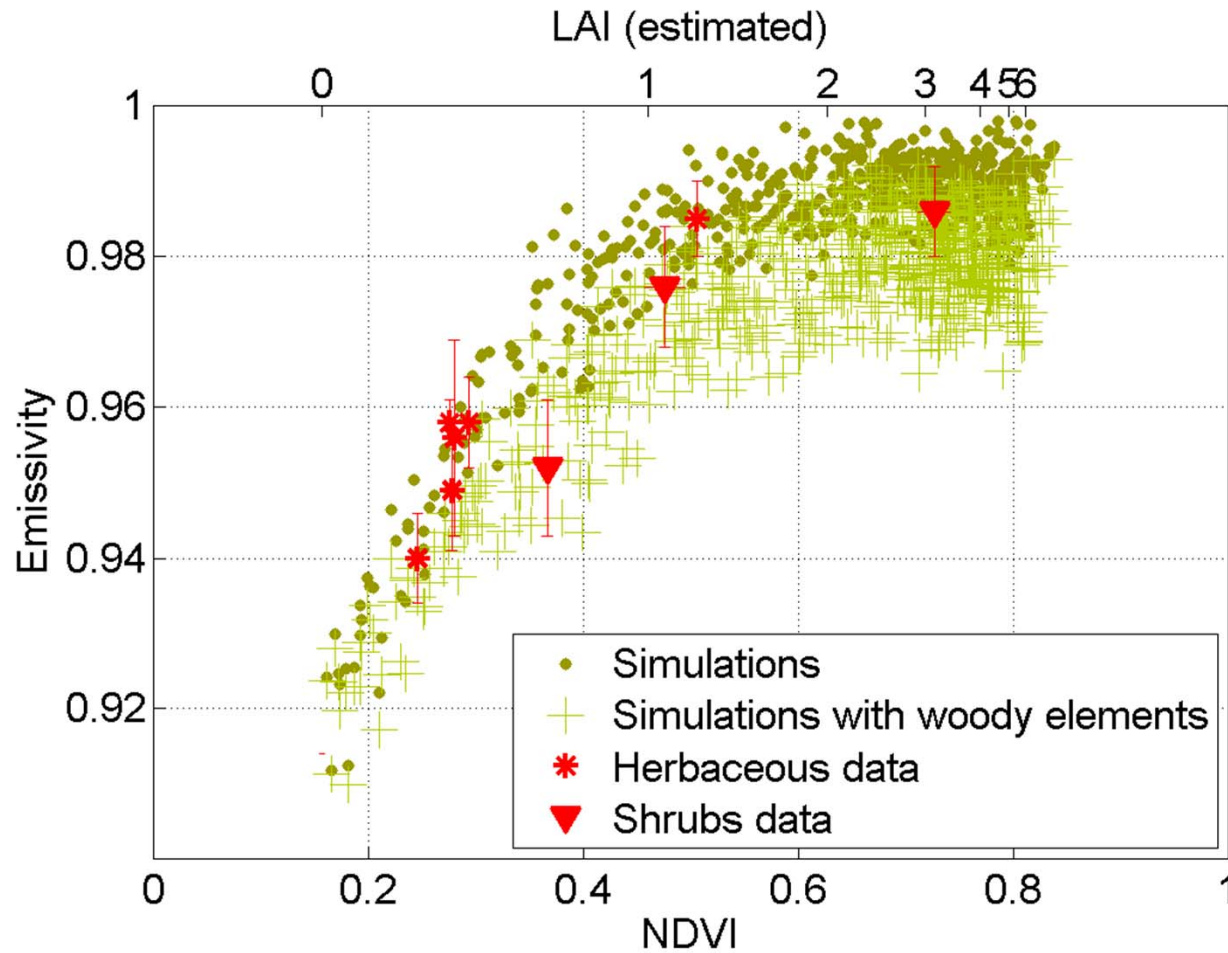
Evaluation of SAIL-Thermique: Alpilles + Barrax (8-14 μm) [crops]



Evaluation of SAIL-Thermique: van de Griend and Owe 1993 (8-14 μm)
[herbaceous, shrubs]



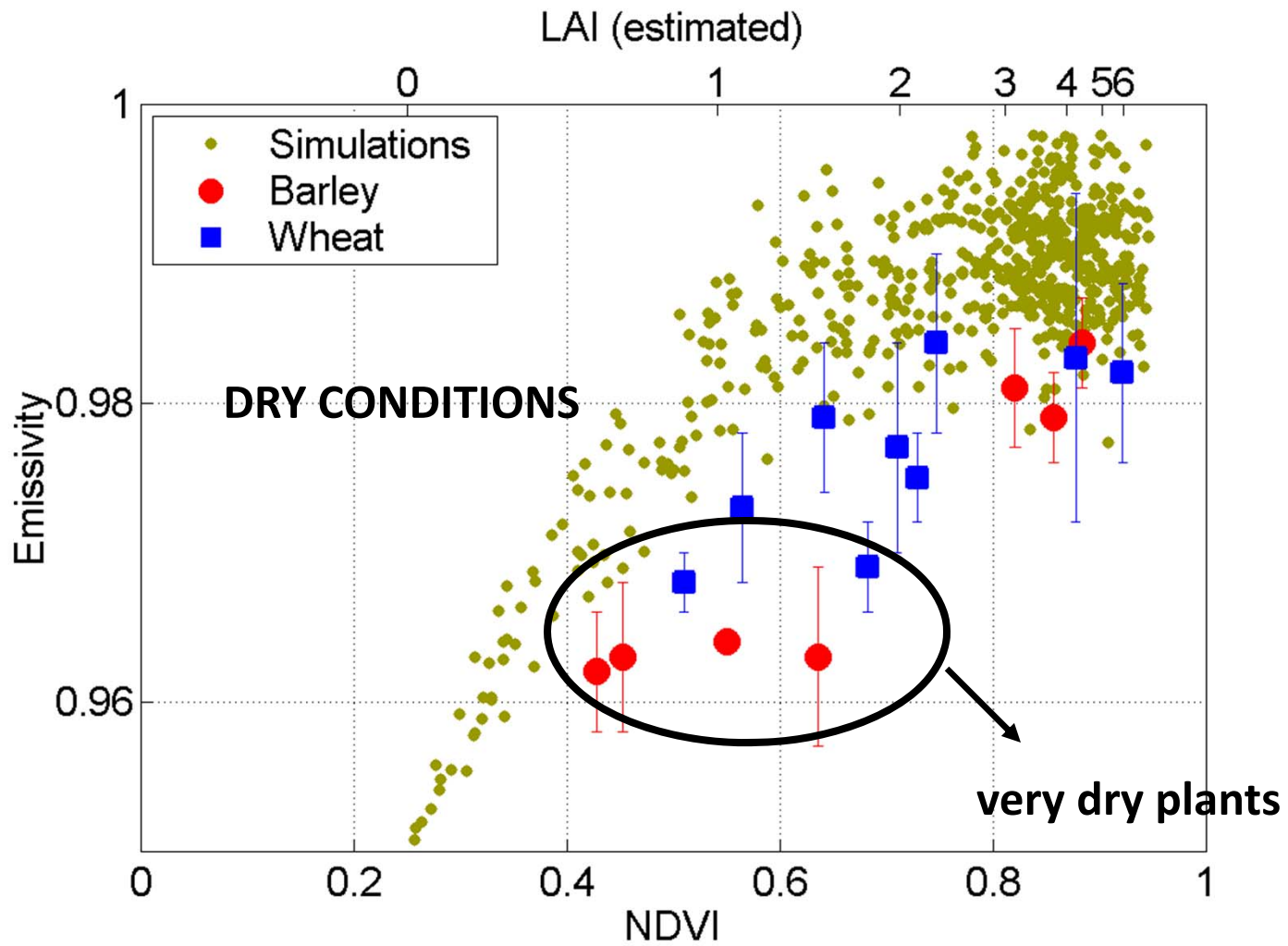
Evaluation of SAIL-Thermique: van de Griend and Owe 1993 (8-14 μm)
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Evaluation of SAIL-Thermique:

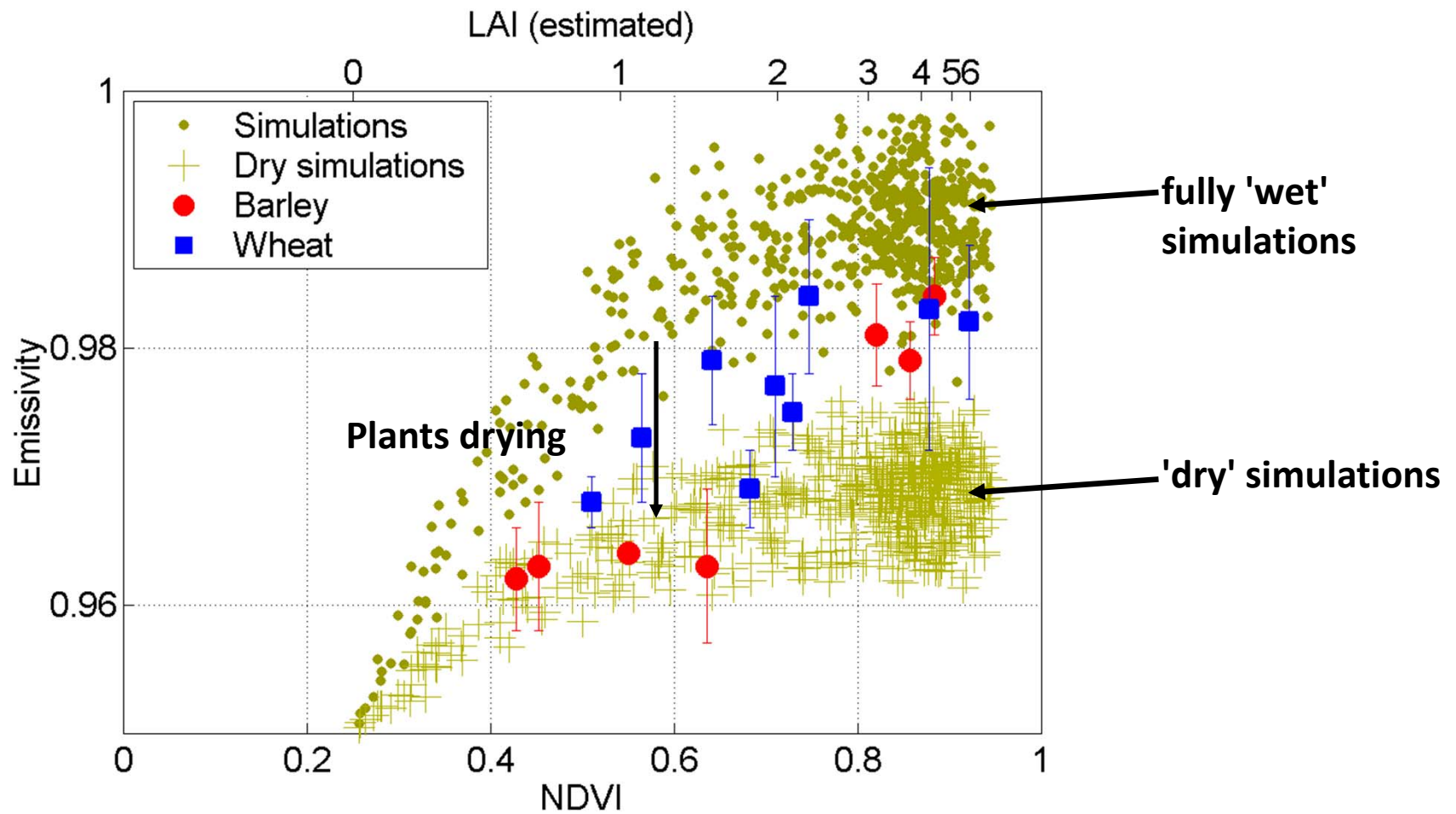
Marrakech 2003 (8-13 μm)

[dry cereals]



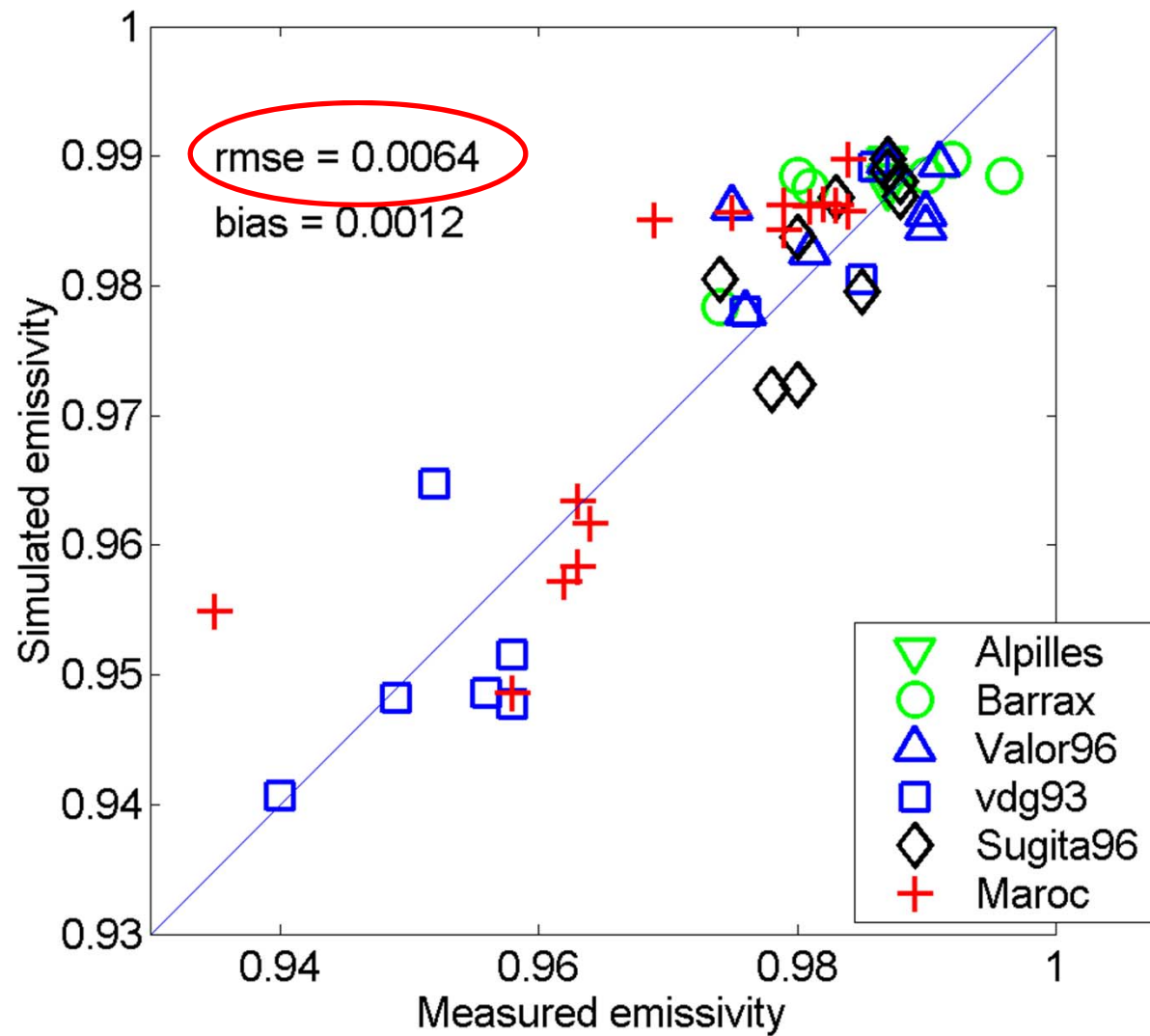
Impact of leaf drying

→ leaf emissivity is lower for dry leaf



All data together

simulation for mean values (leaf emissivity = 0.97 (wet) and 0.91 (dry), spherical canopy)



Simulation of land surface emissivity spectra

- ❑ LSE spectra are used as background in many methods to estimate LSE value
 - ex: { → the TES method for deriving surface temperature from multispectral data
 - the spectral LSE atlas developed at University of Wisconsin

- ❑ There is no measurements of hyperspectral LSE really available for documentation or evaluation

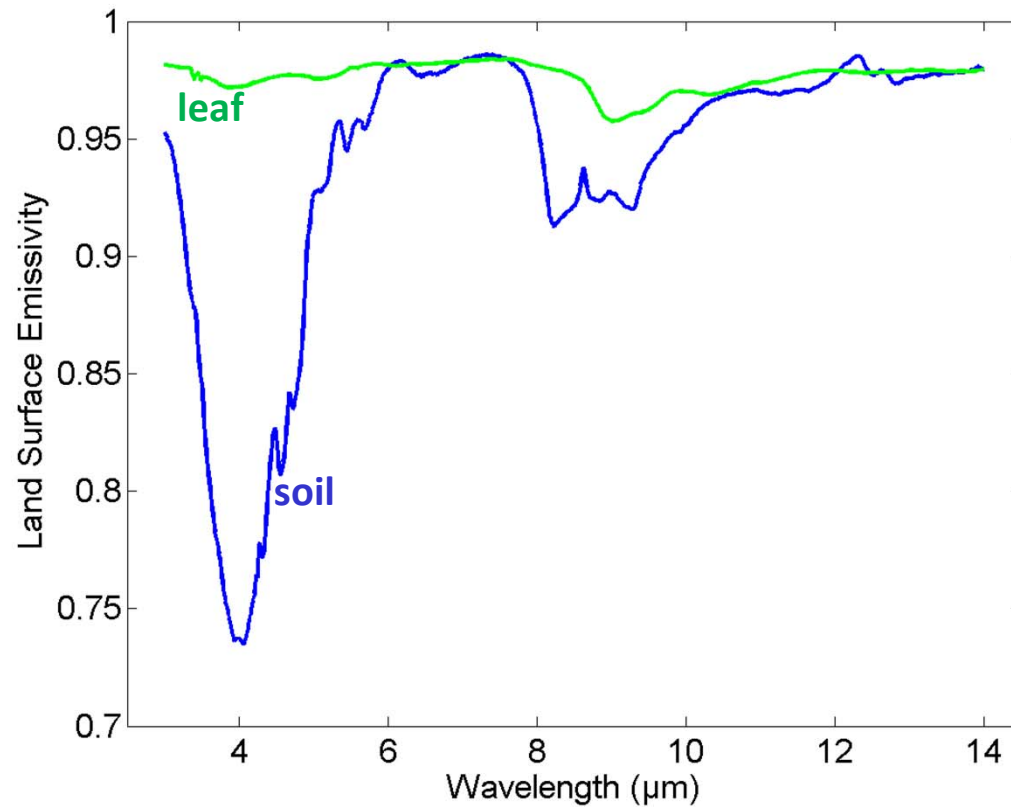
- ❑ we propose to use SAIL-Thermique

- ❑ SAIL-Thermique is a monospectral model

- ❑ but it may be used for simulating emissivity at any TIR wavelength as soon as leaf and soil spectral properties are known

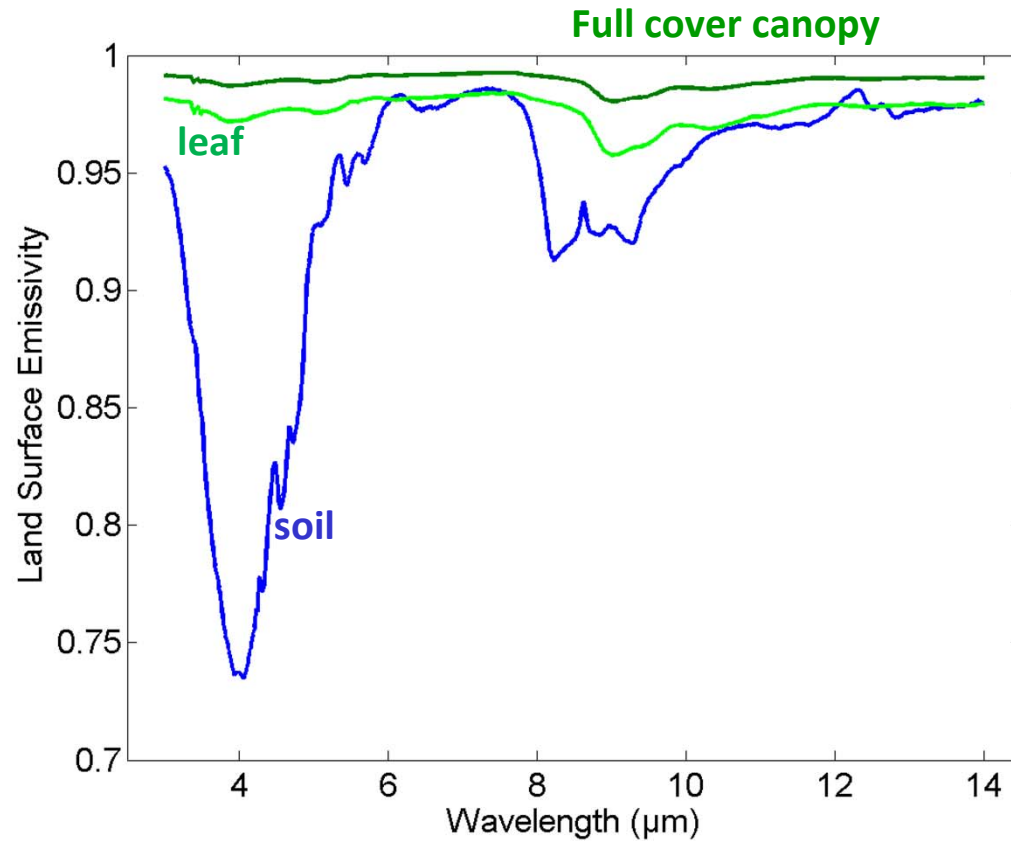
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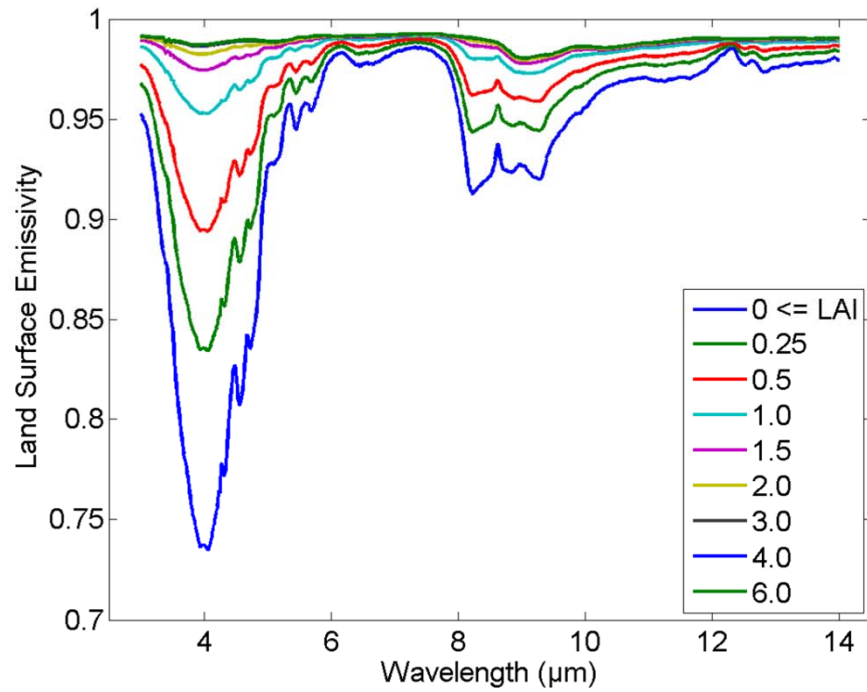
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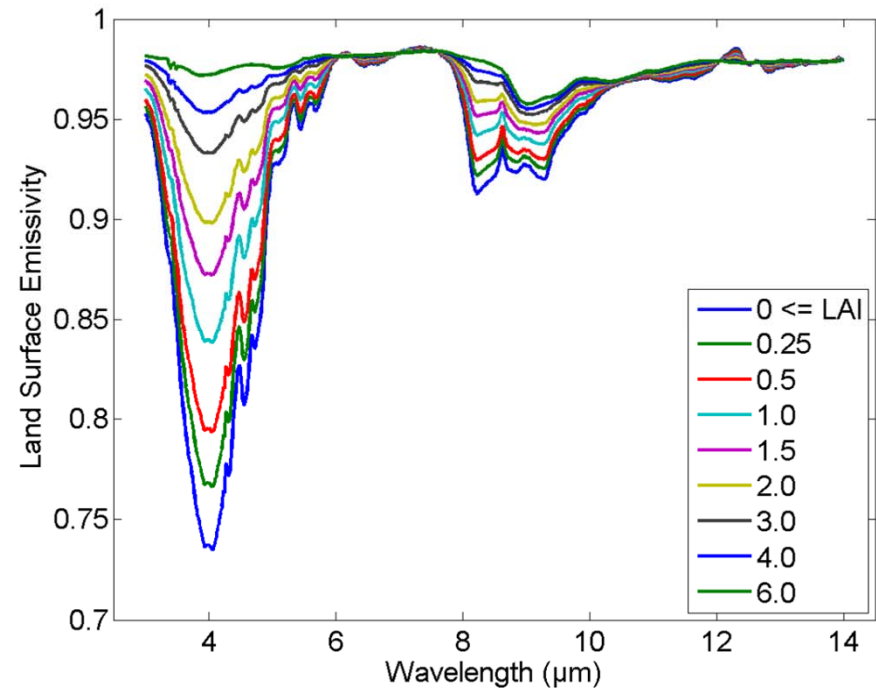


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations

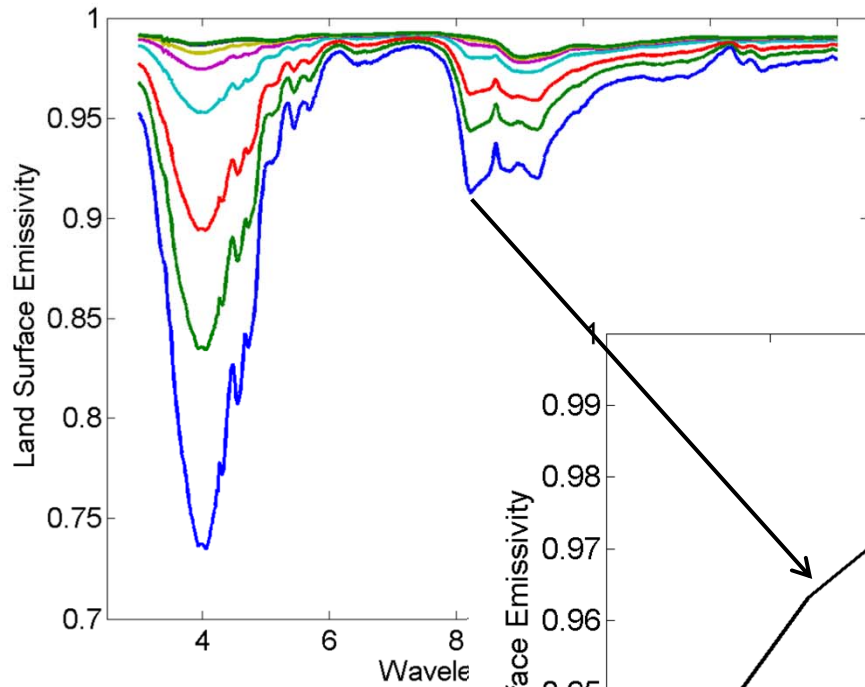


linear mixing from samples

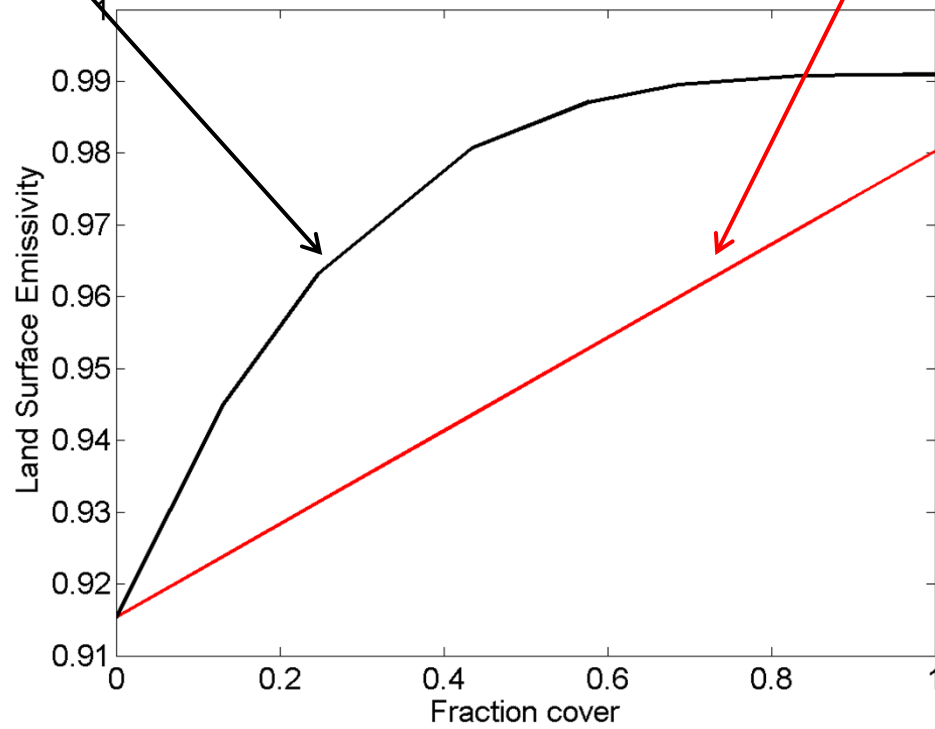
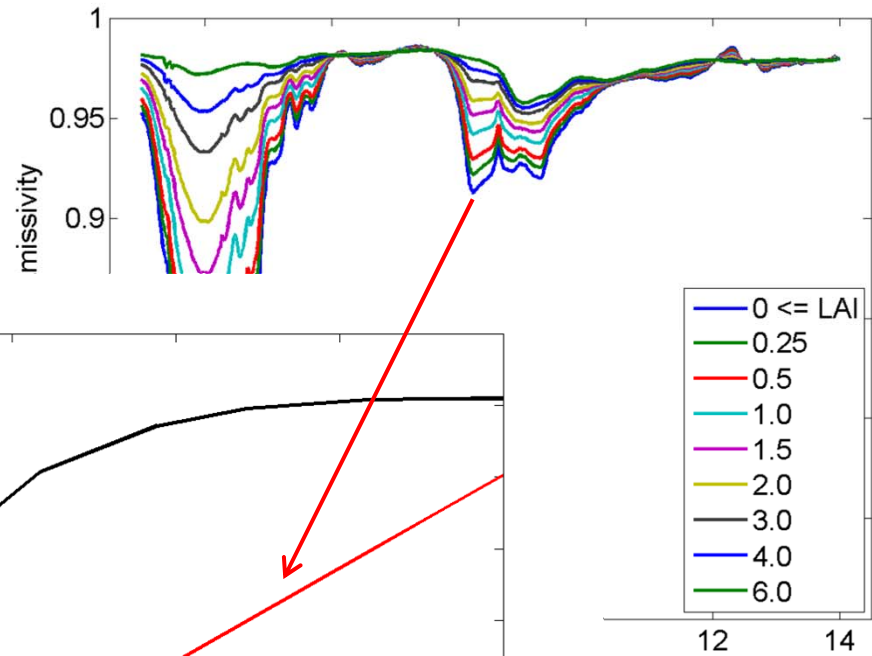


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations

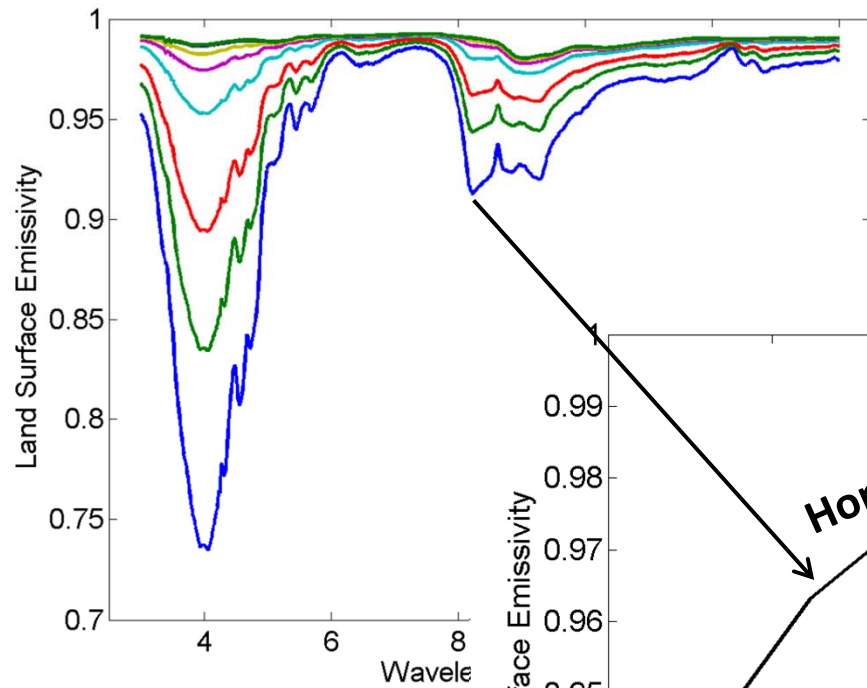


linear mixing from samples

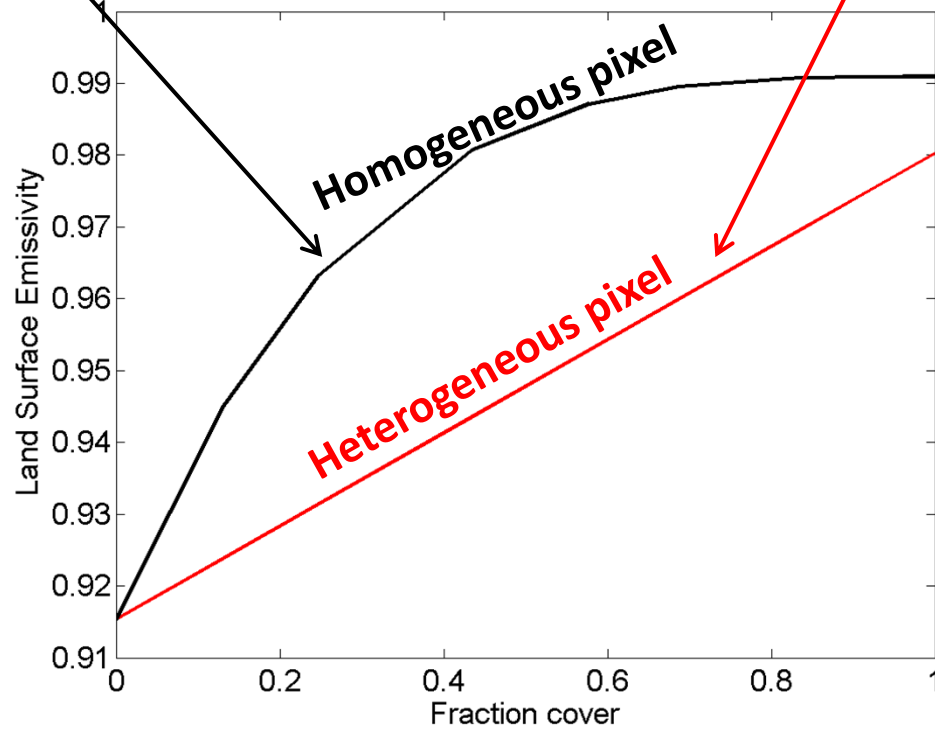
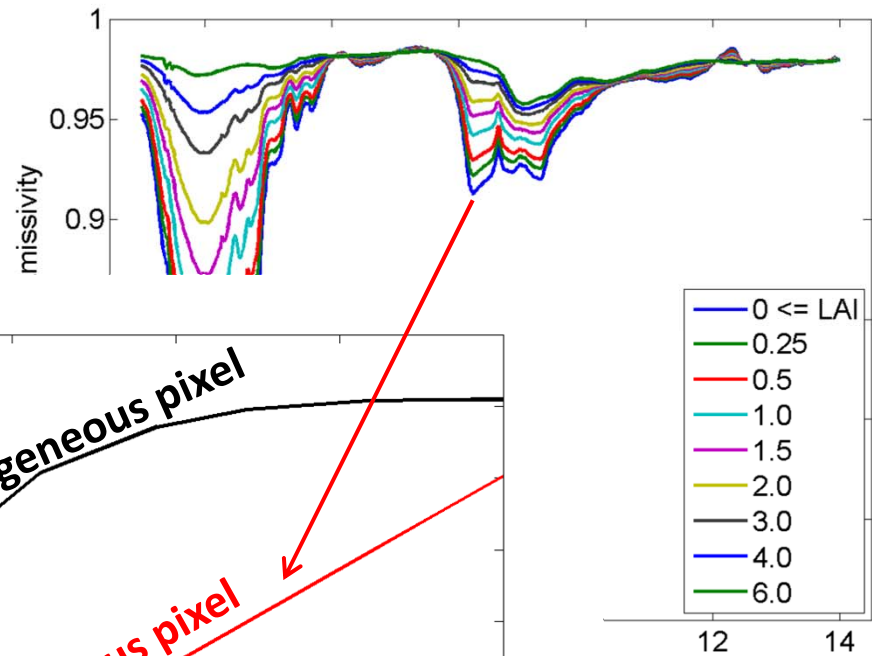


Comparison to standard linear mixing with soil and leaf samples

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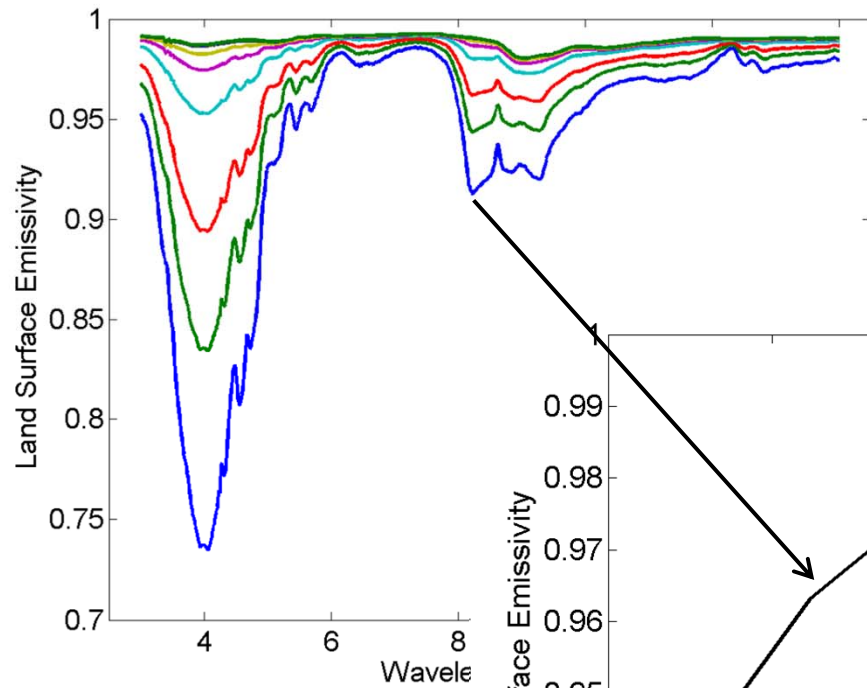


linear mixing from samples

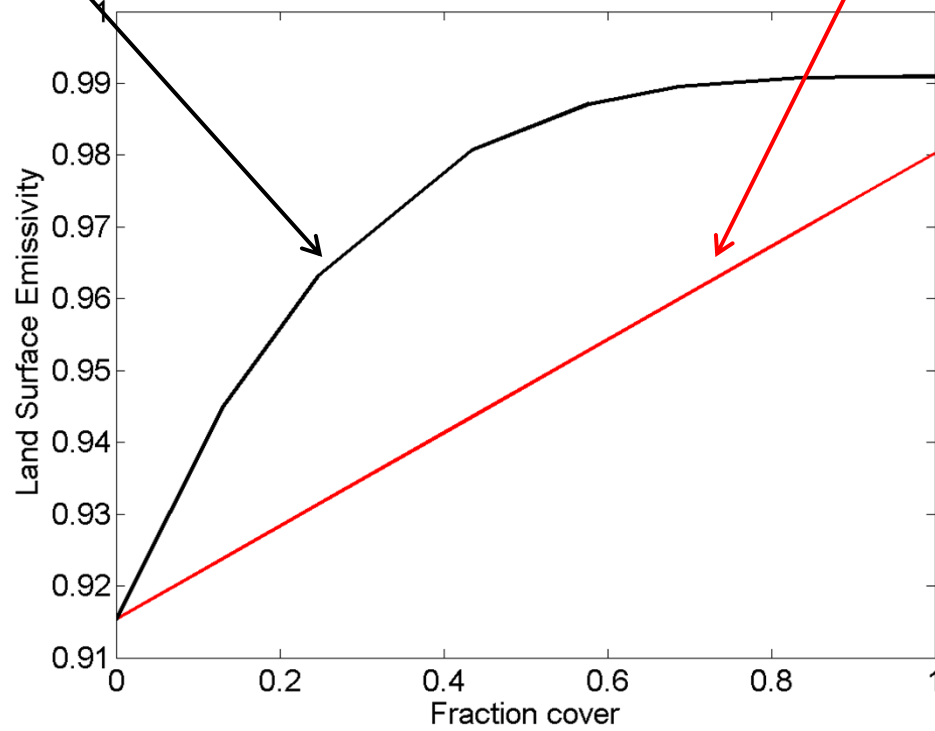
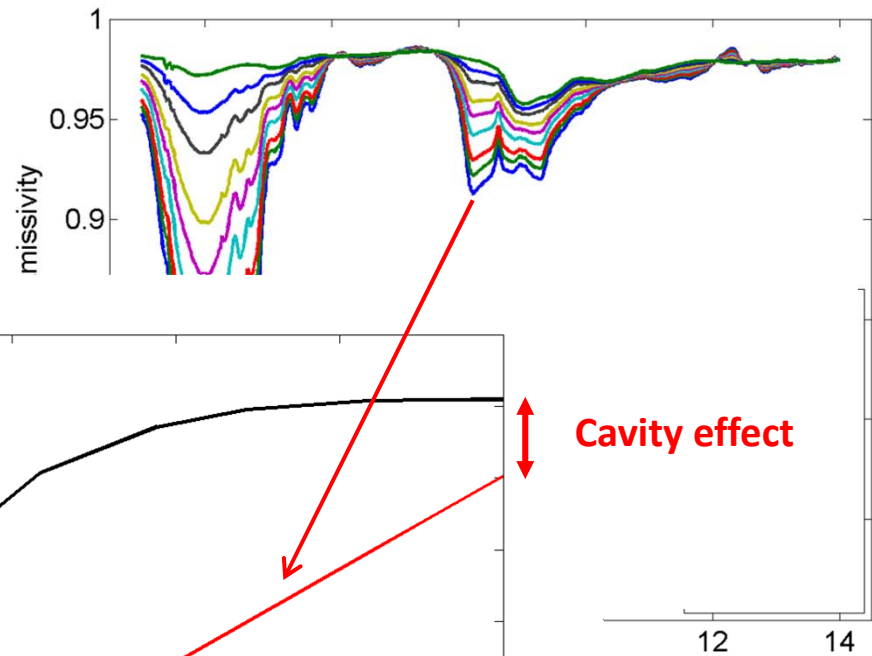


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations



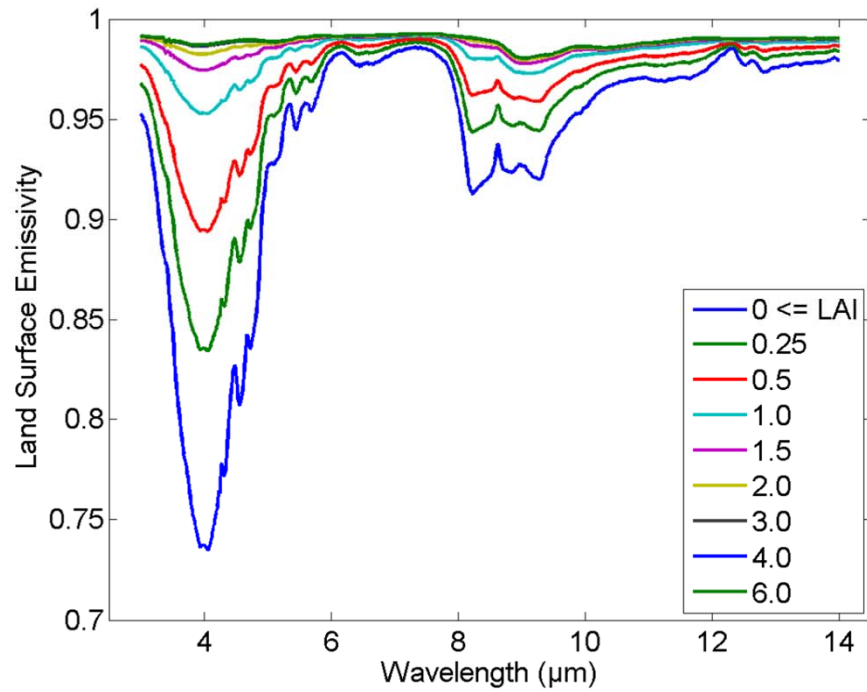
linear mixing from samples



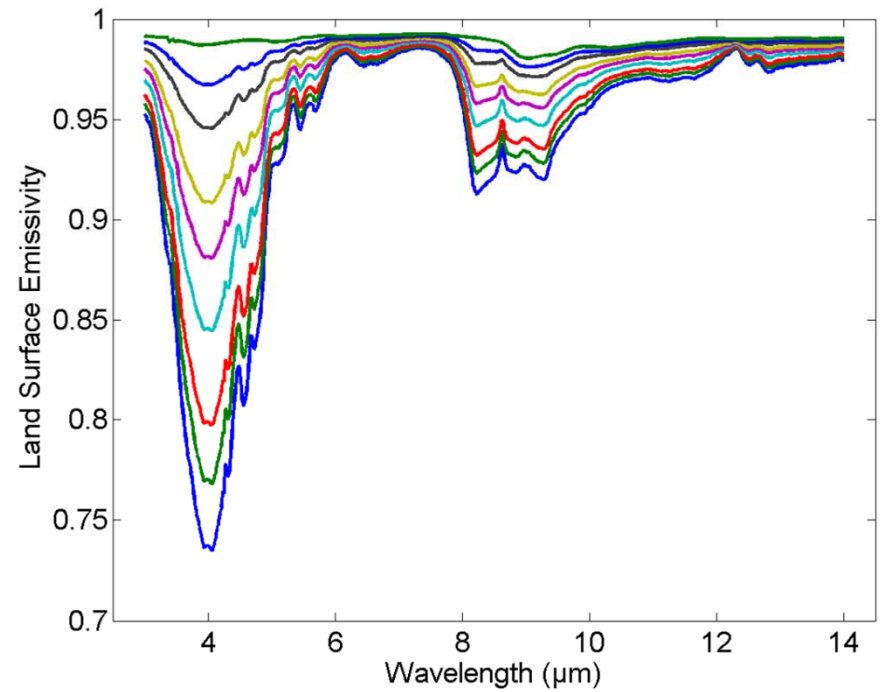
Cavity effect

Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations

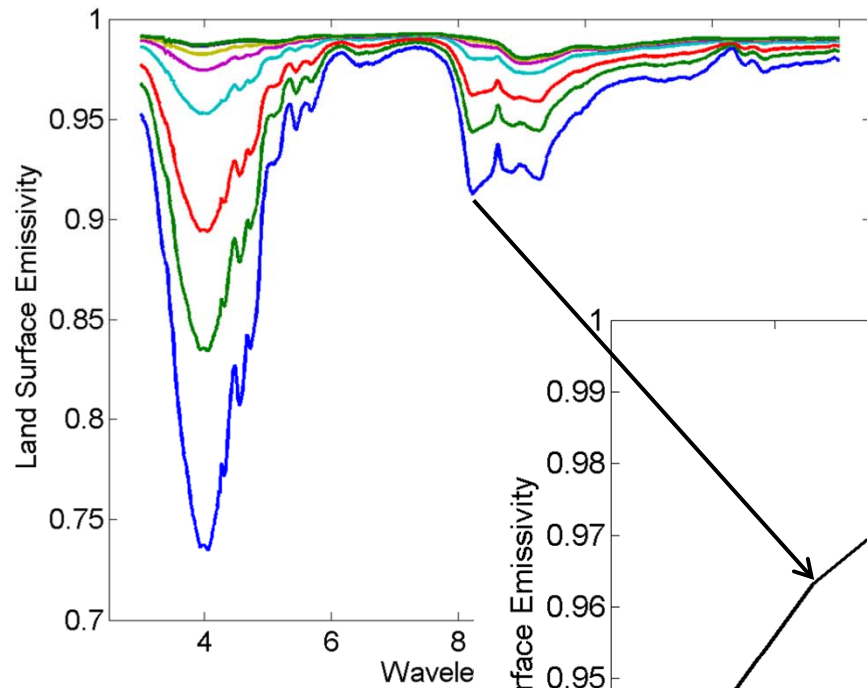


linear mixing from full canopy value

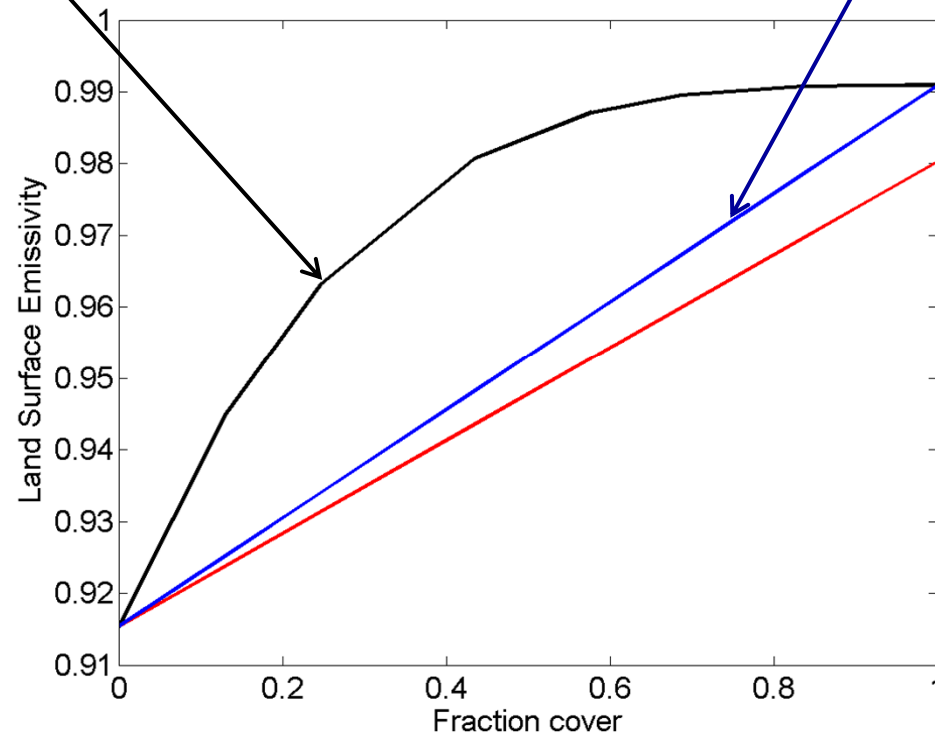
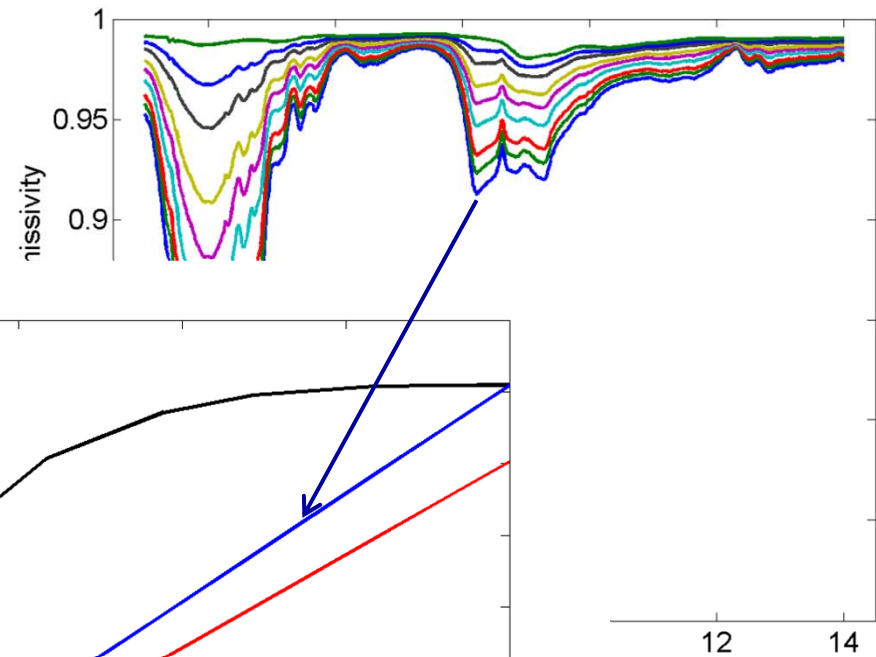


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations

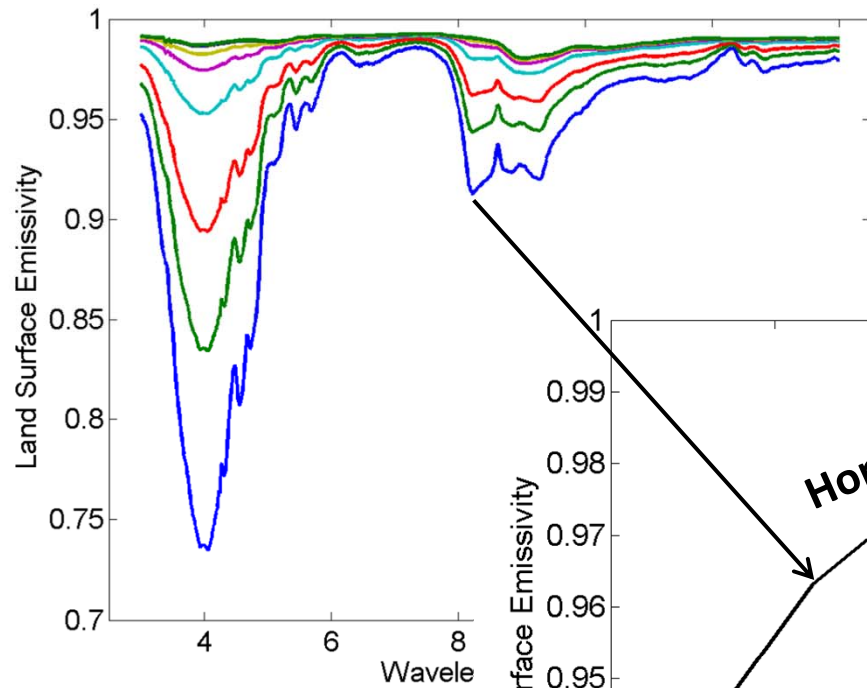


linear mixing from full canopy value

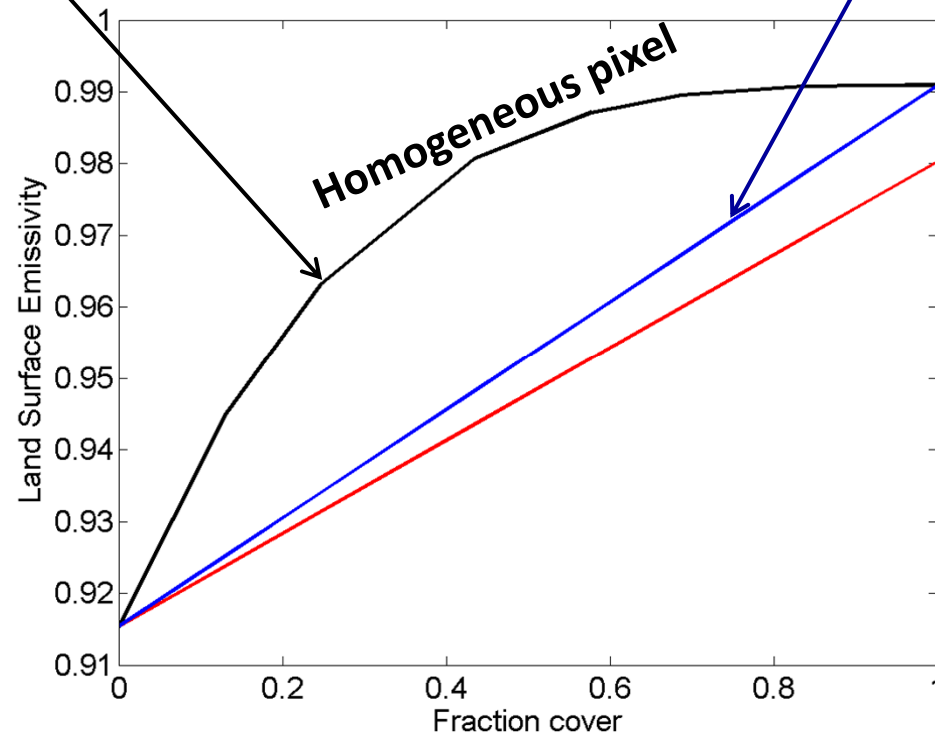
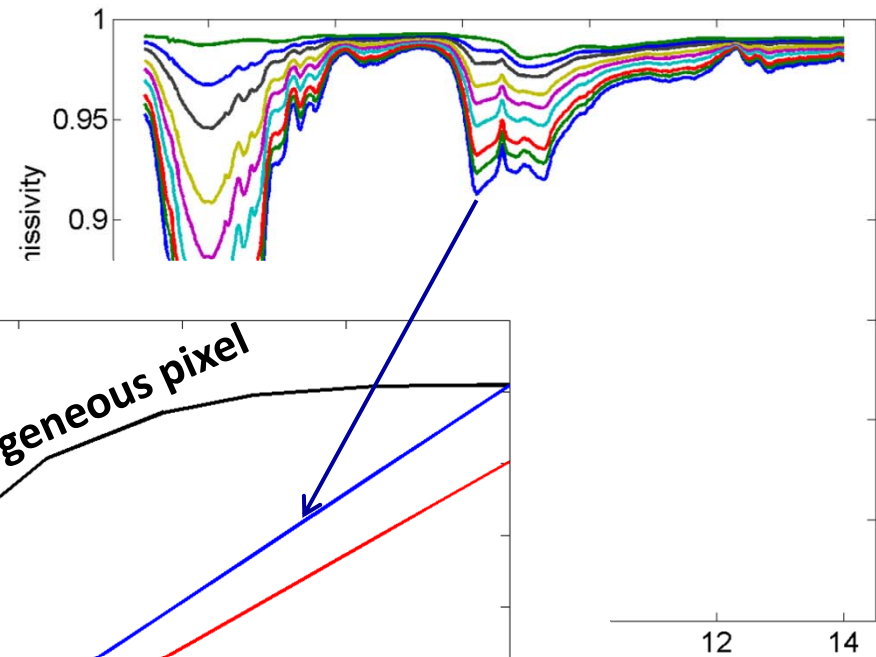


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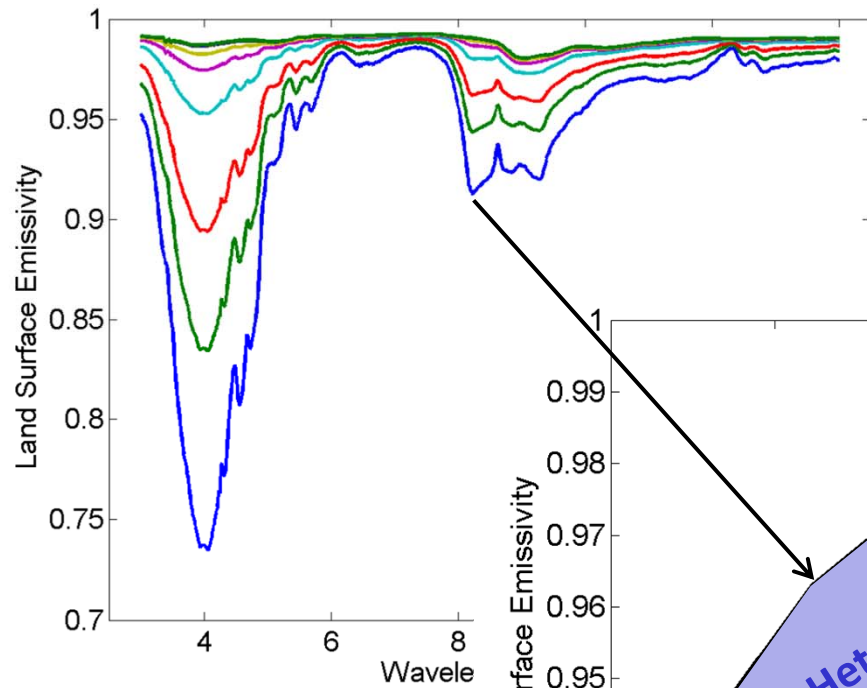


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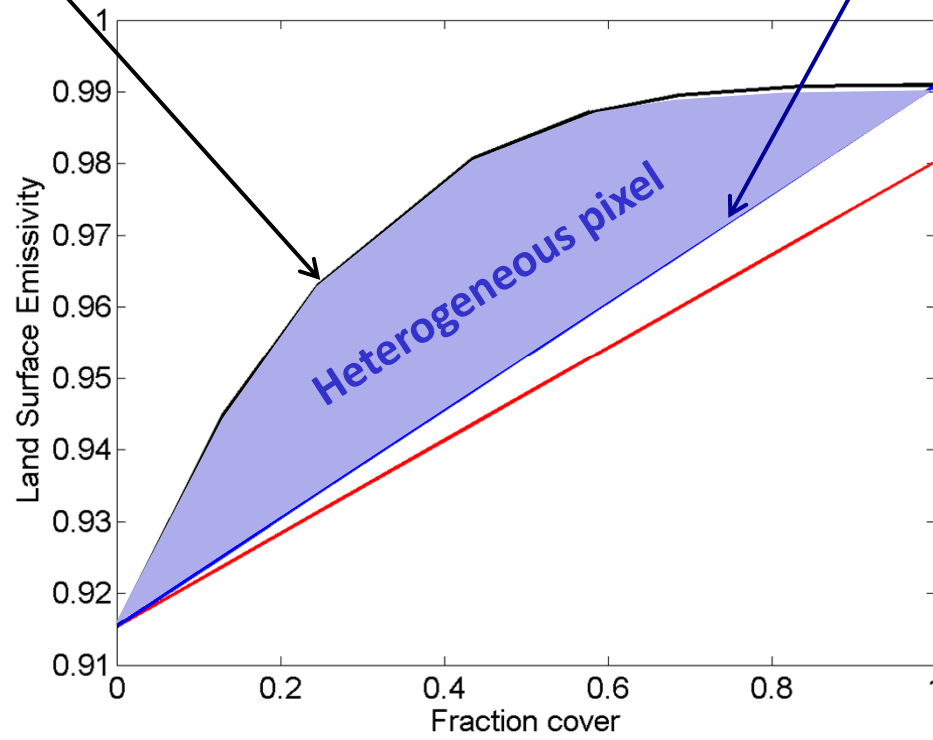
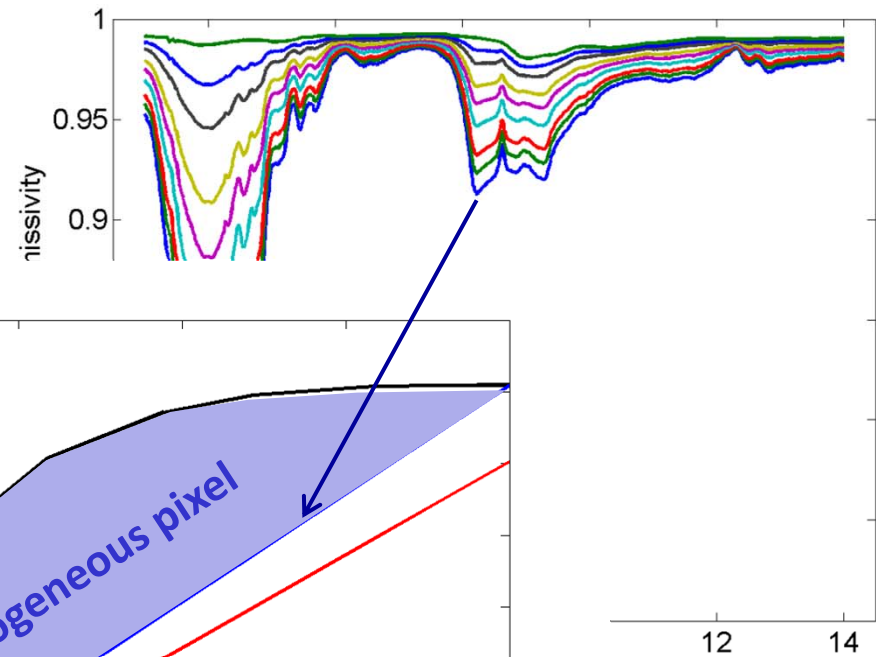


Comparison to standard linear mixing with soil and leaf samples

Radiative transfer calculations



linear mixing from full canopy value

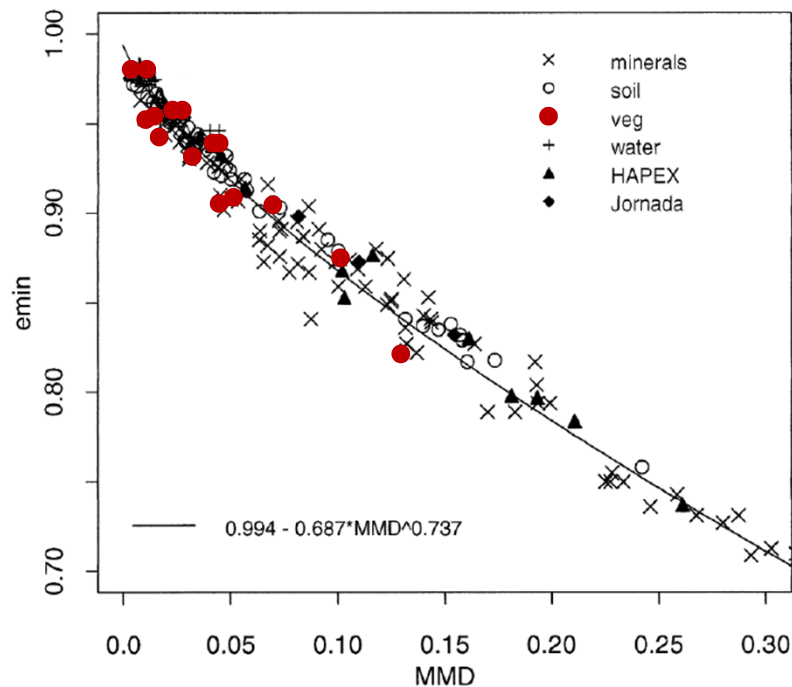


Application to the Temperature – Emissivity Separation (TES) algorithm

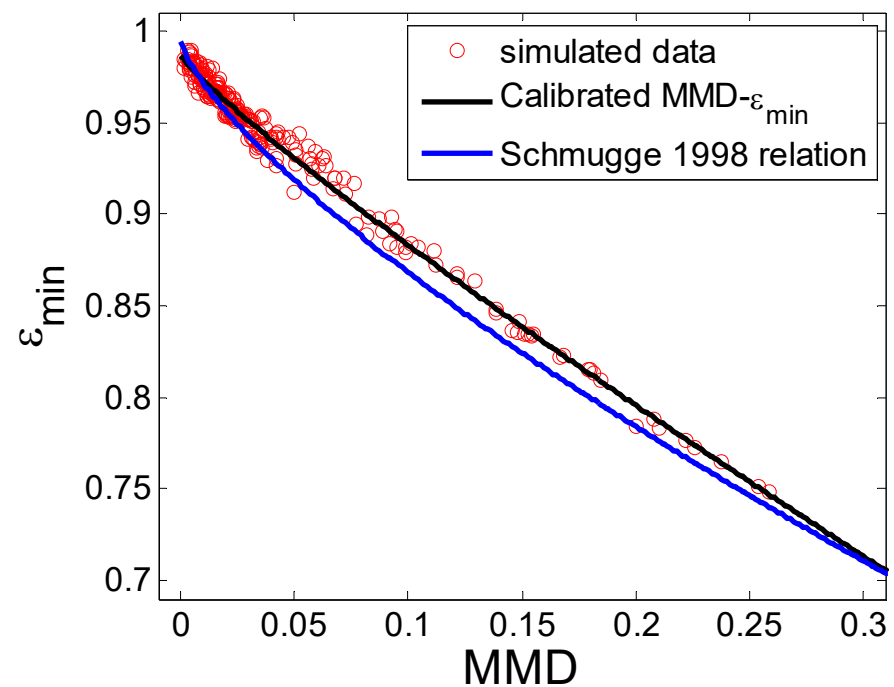
Jacob et al., RSE, 2017

- ❑ Simulation of land surface emissivity spectra for vegetation surfaces
- ❑ Training of the MMD - ϵ_{\min} relationship used in the TES algorithm for ASTER
- ❑ Evaluation of the new algorithm for emissivity and temperature retrievals

Original relation (Schmugge et al. 1998)



(Jacob et al. 2017)



Application to the TES algorithm

Evaluation of the new algorithm for emissivity and temperature retrievals

RMSE (Bias)	Channel 1 8.28 μm	Channel 2 8.63 μm	Channel 3 9.07 μm	Channel 4 10.65 μm	Channel 5 11.28 μm	Ts
Schmugge et al.	0.015 (0.009)	0.013 (0.008)	0.011 (0.007)	0.011 (0.008)	0.011 (0.008)	0.60 K (-0.37 K)
New	0.008	0.007	0.006	0.006	0.006	0.33 K

When accounting of canopy impact on LSE

- > error on LSE and LST retrieval were reduced by a factor 2
- > retrieved LSE were increased
- > retrieved LST were decreased

Concluding remarks

- ❑ Yes, it is possible to use a “standard” Radiative Transfer models for simulating land surface emissivity in presence of vegetation canopy

- ❑ The SAIL-Thermique model is a simple model that can be applied to homogeneous canopy

- ❑ The model may be used for helping in the analysis of TIR multispectral data
 - variation of emissivity as a function of plant canopy structure and sensor characteristics
 - in an inverse mode for deriving plant component spectra

- ❑ The model was used for deriving a new version of the TES algorithm by improving the representativity of the $MMD - \epsilon_{\min}$ relationship for vegetated areas.

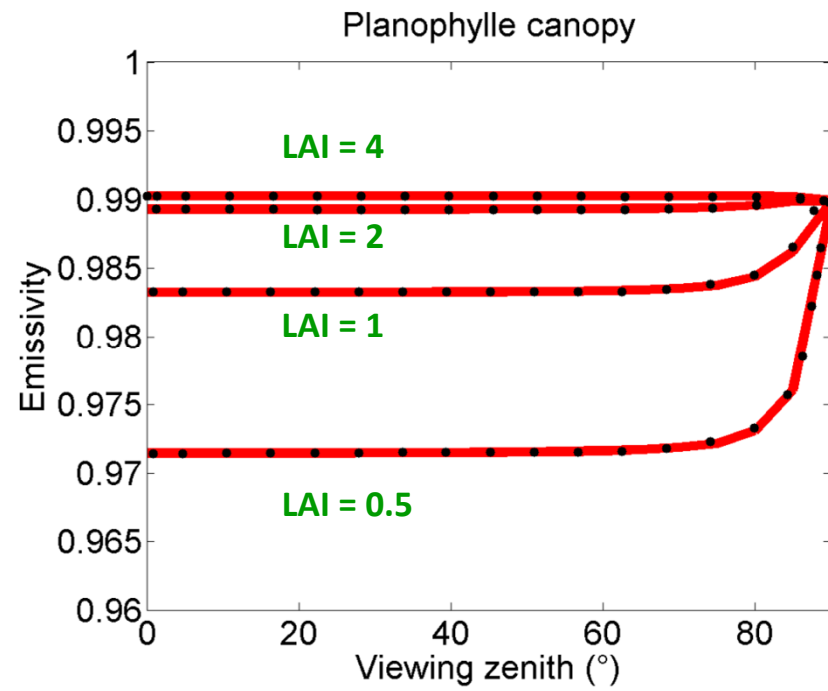
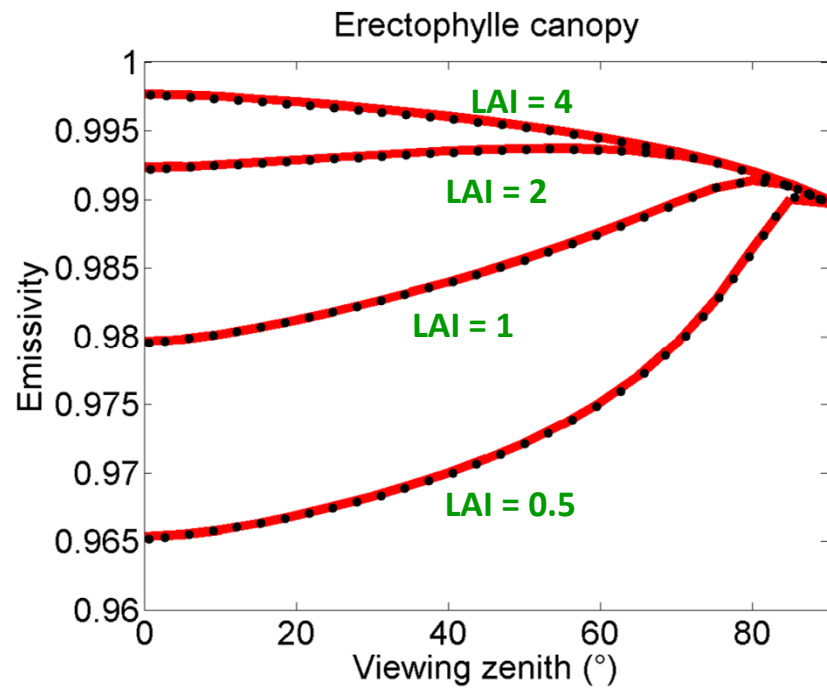
Can be applied to any multispectral sensors (MODIS, MISTIGRI, HypsIRI, MASTER, HyTES...)

- ❑ Would this be useful for TIR hyperspectral atmospheric sounders ?

- ❑ We have to go further in understanding leaf and soil optical properties in the thermal infrared domain (e.g. response to drying) and we need measurements on vegetation

Evaluation of SAIL-Thermique against 4SAIL

— SAIL-Thermique
•••• 4SAIL



Evaluation of SAIL-Thermique against 4SAIL

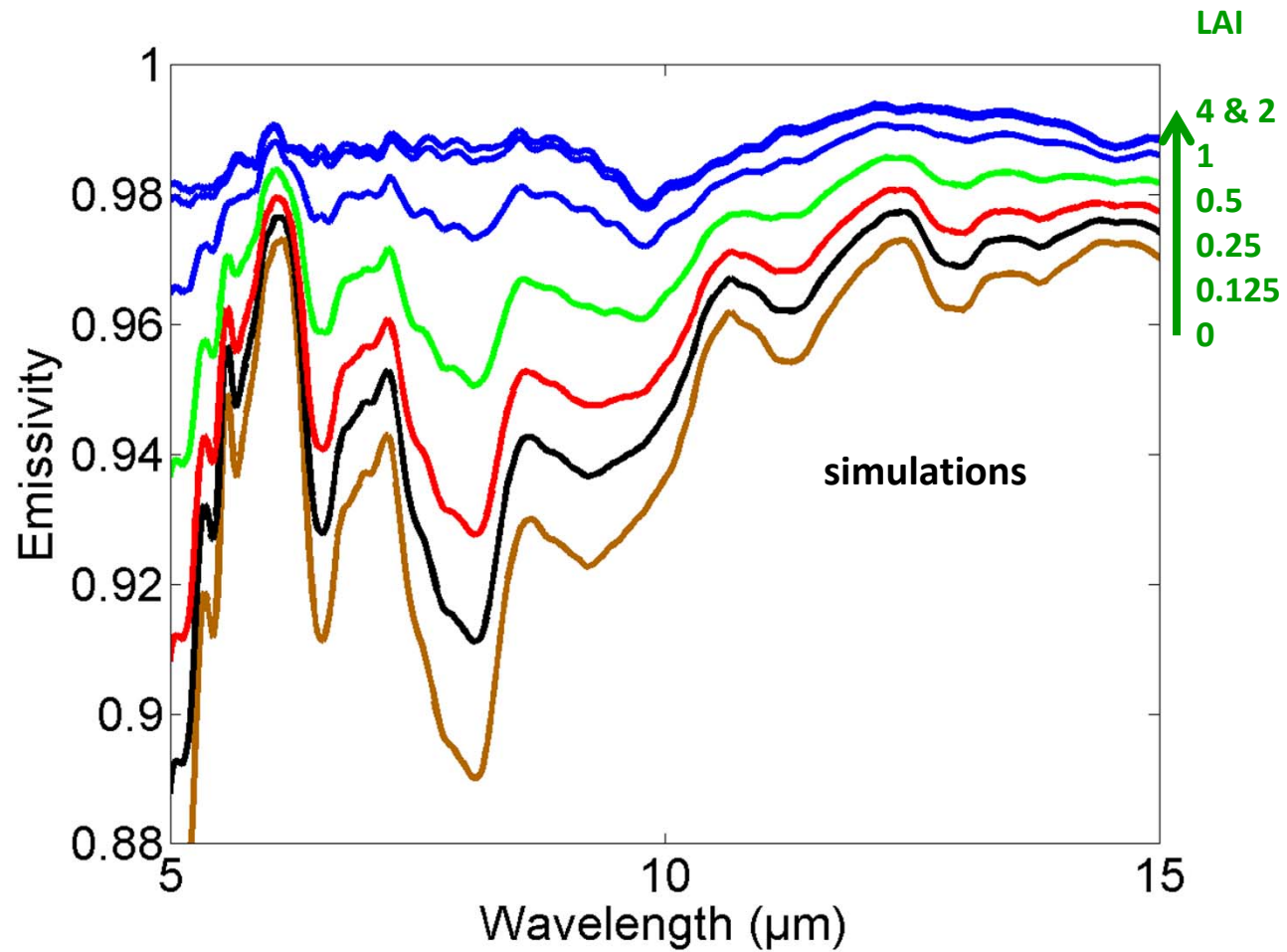
SAIL-Thermique:
$$\varepsilon = 1 - \rho_{sd} - \frac{\tau_{ss}r_{sd} + \tau_{sd}r_{dd}}{1 + \rho_{dd}r_{dd}} \tau_{dd}$$

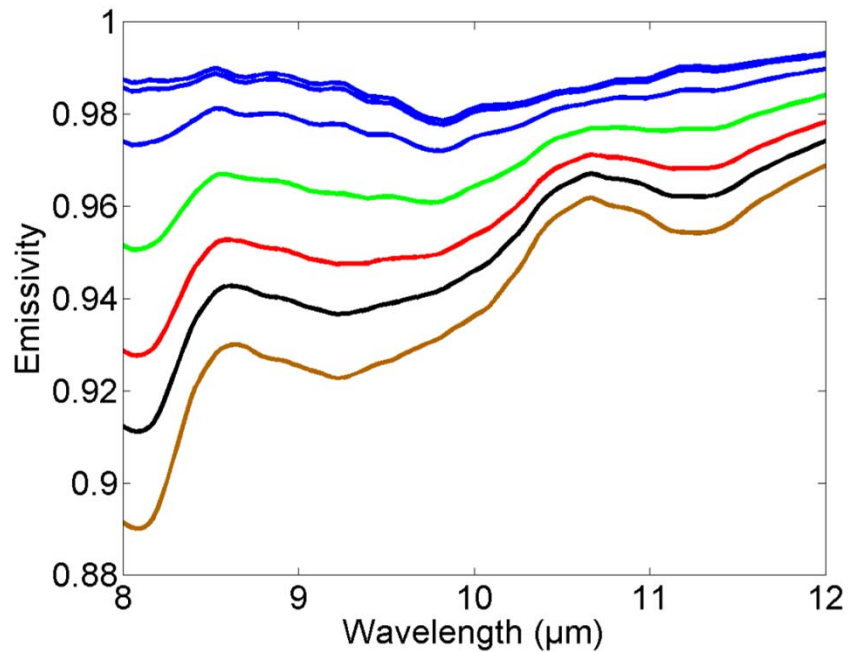
4SAIL:
$$\varepsilon_o = \gamma_o + \frac{(\tau_{do} + \tau_{oo})}{1 - r_s \rho_{dd}} r_s \gamma_d + \frac{(\tau_{do} + \tau_{oo})}{1 - r_s \rho_{dd}} \varepsilon_s.$$
$$\gamma_d = 1 - \rho_{dd} - \tau_{dd}$$
$$\gamma_o = 1 - \rho_{do} - \tau_{do} - \tau_{oo}.$$

Evaluation with multispectral measurements

Soybean data in Avignon, with different LAI

Leaf and soil spectra and 6 band radiometer measurements above canopy

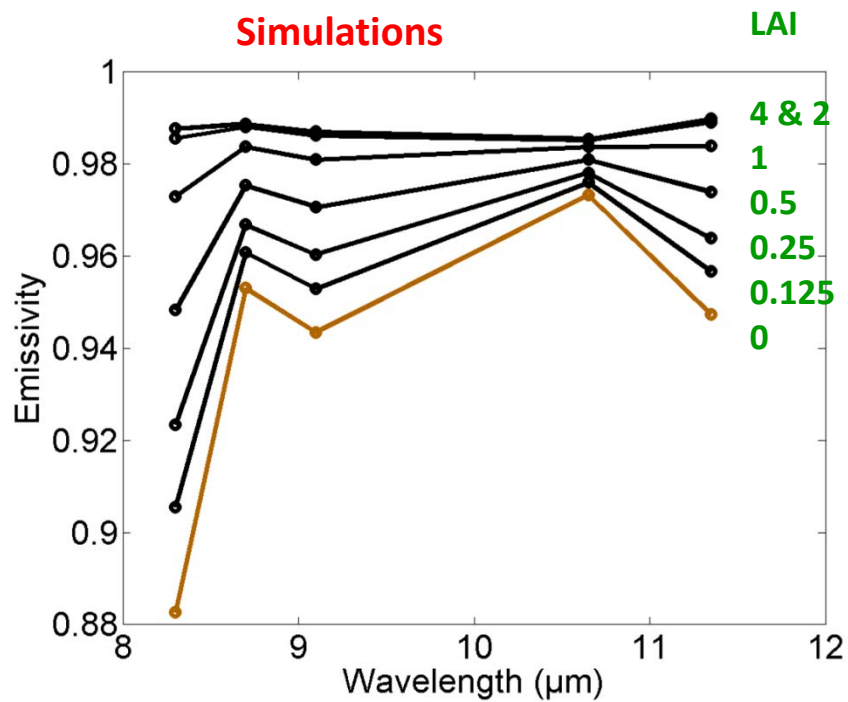




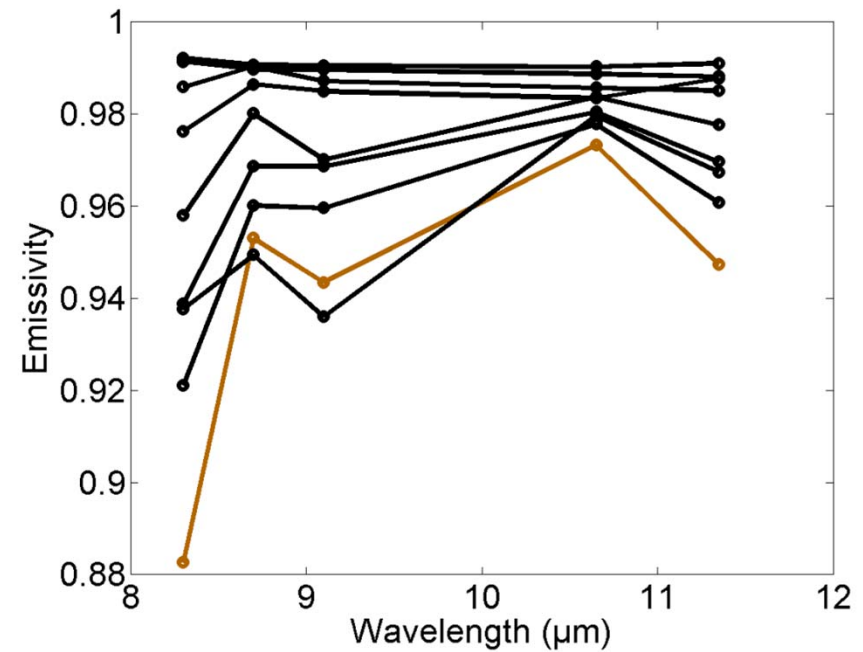
Evaluation with multispectral measurements

Soybean data in Avignon, with different LAI

TES method applied from radiometric measurements above canopy in ASTER bands



Estimations with TES measurements





Available online at www.sciencedirect.com



Remote Sensing of Environment xx (2007) xxx–xxx

Remote Sensing
of
Environment

www.elsevier.com/locate/rse

Spectral reflectance and emissivity features of broad leaf plants: Prospects for remote sensing in the thermal infrared (8.0–14.0 μm)[☆]

Beatriz Ribeiro da Luz^{*}, James K. Crowley

U. S. Geological Survey, MS 954, 12201 Sunrise Valley Drive, Reston, VA 20192, United States

Received 23 October 2006; received in revised form 18 January 2007; accepted 20 January 2007

Remote Sensing of Environment 114 (2010) 404–413



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journal homepage: www.elsevier.com/locate/rse



Identification of plant species by using high spatial and spectral resolution thermal infrared (8.0–13.5 μm) imagery[☆]

Beatriz Ribeiro da Luz^{*}, James K. Crowley

Influence of Water Content on Spectral Reflectance of Leaves in the 3–15- μm Domain

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Modeling directional–hemispherical reflectance and transmittance of fresh and dry leaves from 0.4 μm to 5.7 μm with the PROSPECT-VISIR model

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**Influence of soil moisture content on spectral reflectance of bare soils
in the 0.4–14 μm domain**

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Reassessment of the temperature-emissivity separation from multispectral thermal infrared data: Introducing the impact of vegetation canopy by simulating the cavity effect with the SAIL-Thermique model



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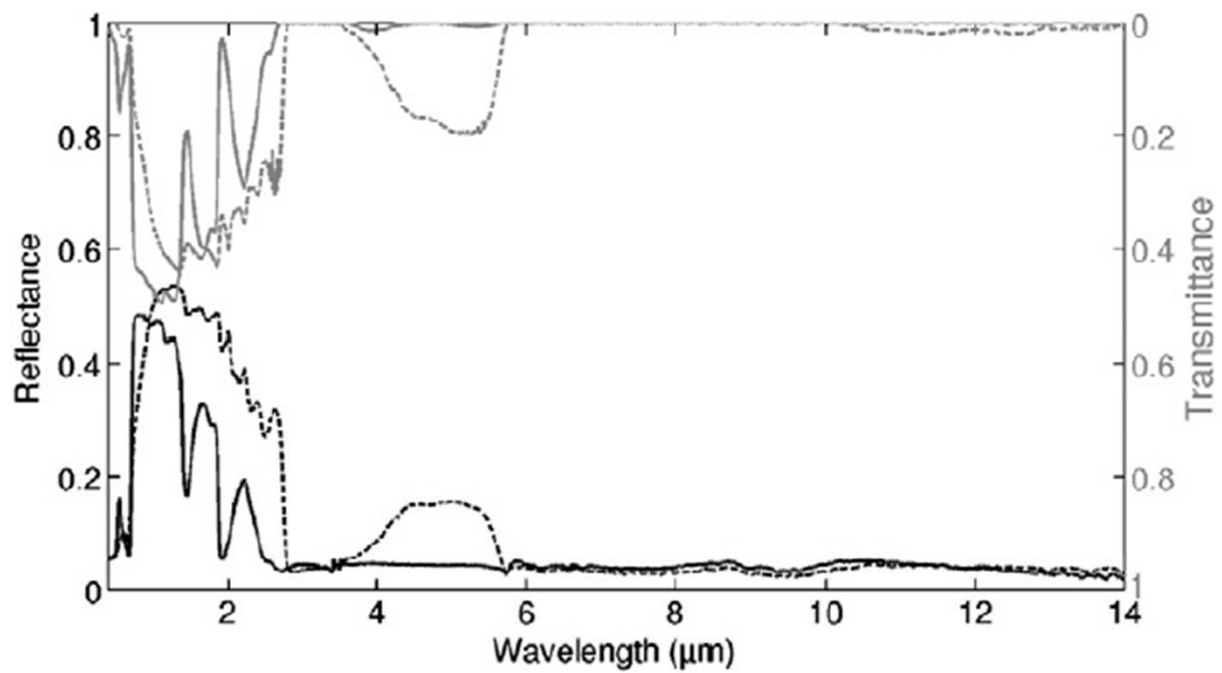


Fig. 3. DHR (black) and DHT (grey) of fresh (plain line) and dry (dashed line) *Catalpa* leaves from the USGS dataset.

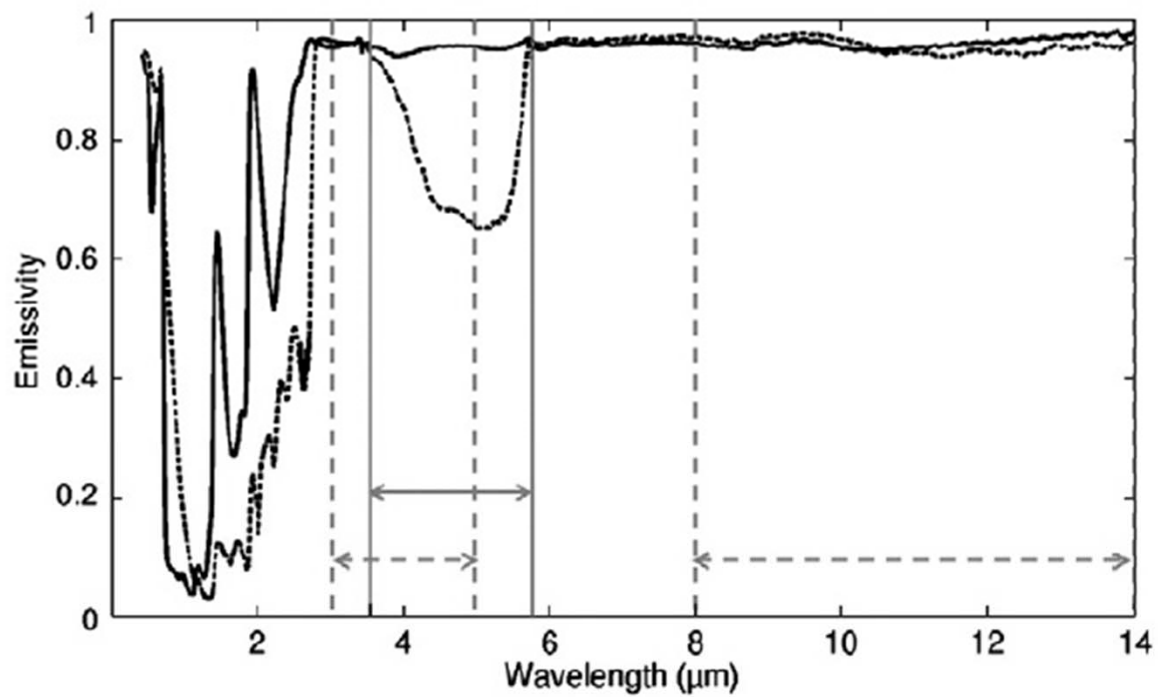


Fig. 6. Emissivity of fresh (plain black line) and dry (dashed black line) *Catalpa* leaves from the USGS dataset. The spectral ranges of interest are marked by lines (3.5–5.7 μm, 3–5 μm, and 8–14 μm). See Table 2 for emissivity statistics for these ranges.

Table 2

Statistics about leaf emissivity in three spectral domains.

Spectral range	Minimum	Maximum	Mean	Standard deviation
<i>Fresh leaves</i>				
3.5–5.7 μm	0.89	0.97	0.95	0.02
3–5 μm	0.92	0.97	0.95	0.01
8–14 μm	0.93	0.98	0.96	0.01
<i>Dry leaves</i>				
3.5–5.7 μm	0.67	0.90	0.79	0.06
3–5 μm	0.75	0.97	0.90	0.06
8–14 μm	0.89	0.96	0.94	0.02

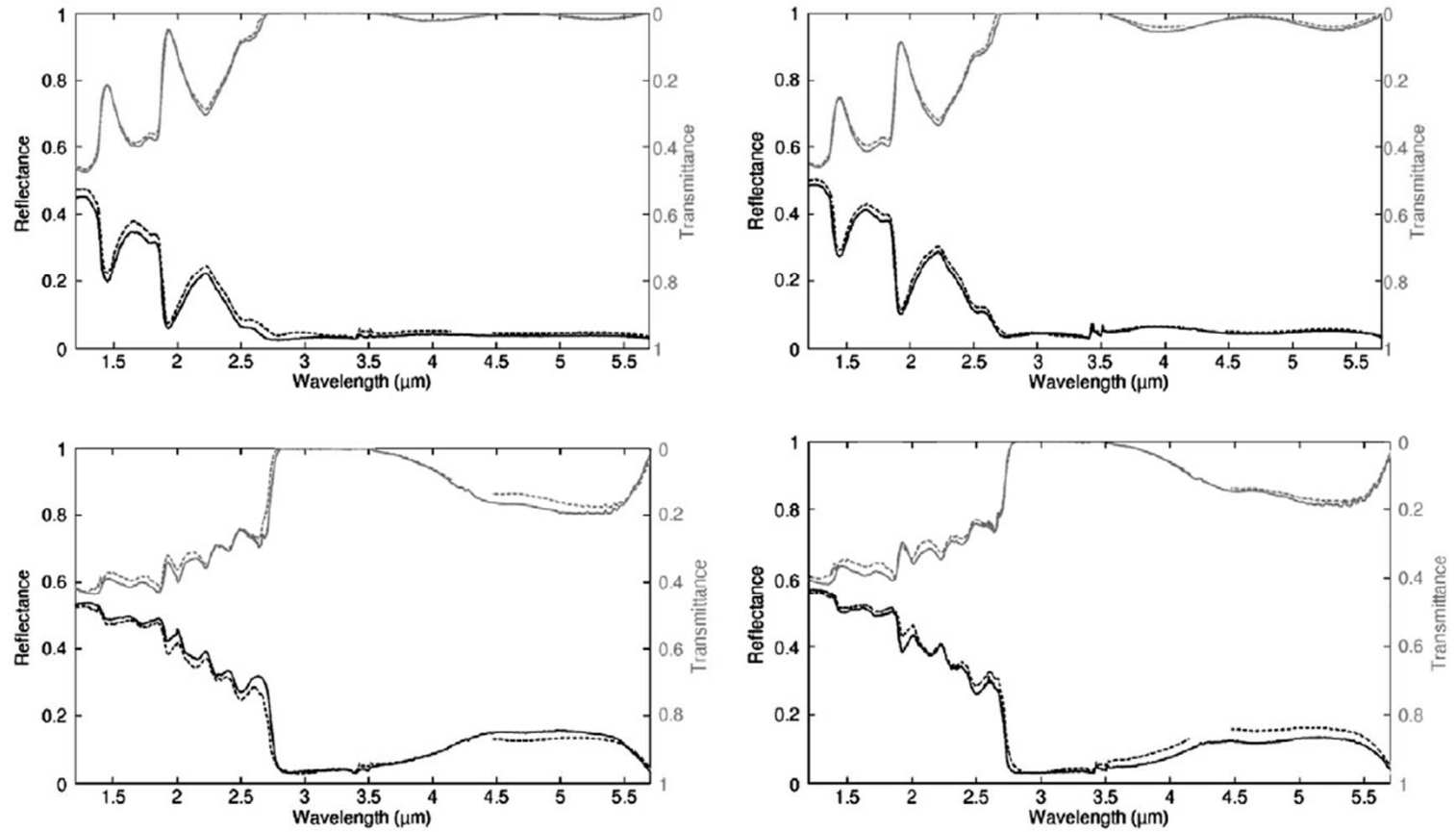


Fig. 10. Simulated (dashed line) vs. measured (plain line) reflectance and transmittance of fresh (top left: *Catalpa*, top right: *Tillia*) and dry (bottom left: *Catalpa*, bottom right: *Acer platanooides*) leaves.

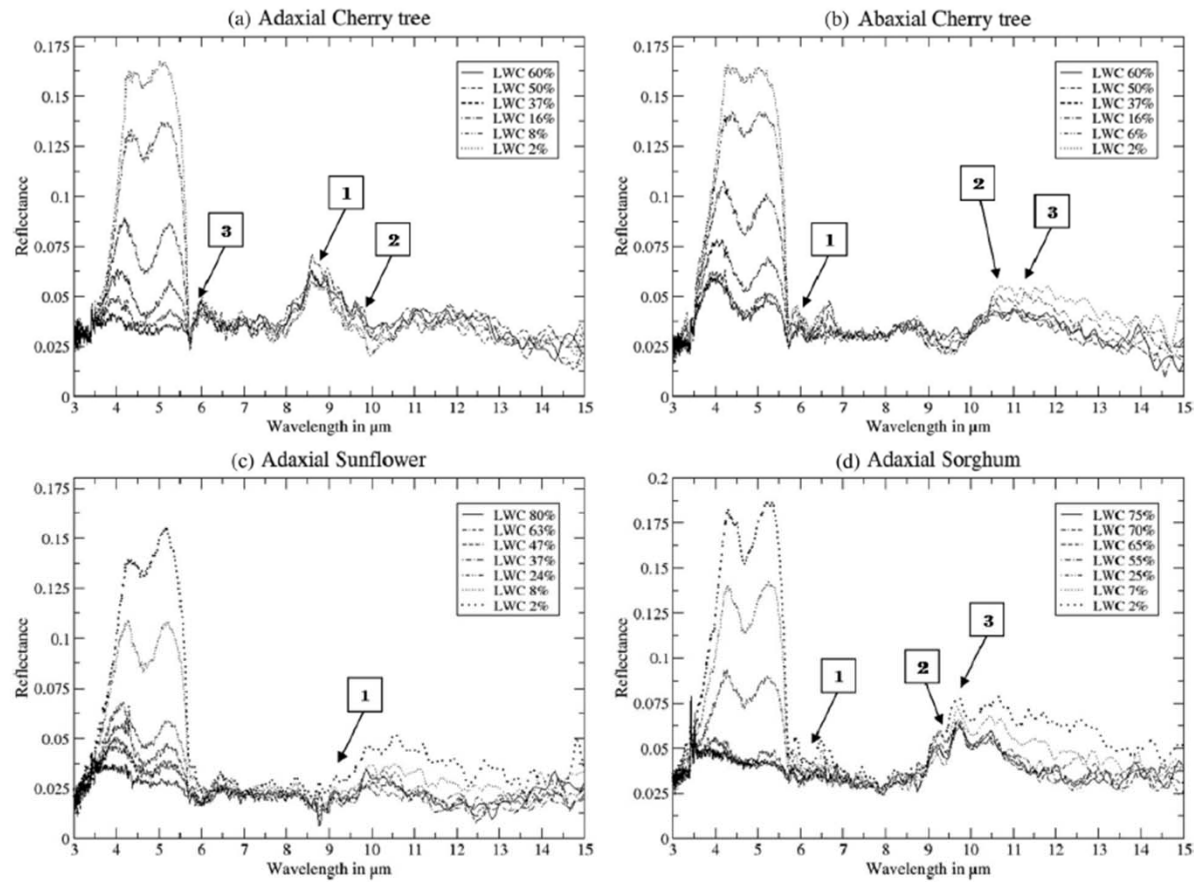


Fig. 2. Spectral reflectances of leaves for several water contents in the thermal domain. (a) Adaxial and (b) abaxial sides of cherry tree, (c) adaxial side of sunflower, and (d) sorghum leaf samples. Arrow labels locate a specific behavior, detailed in the document.

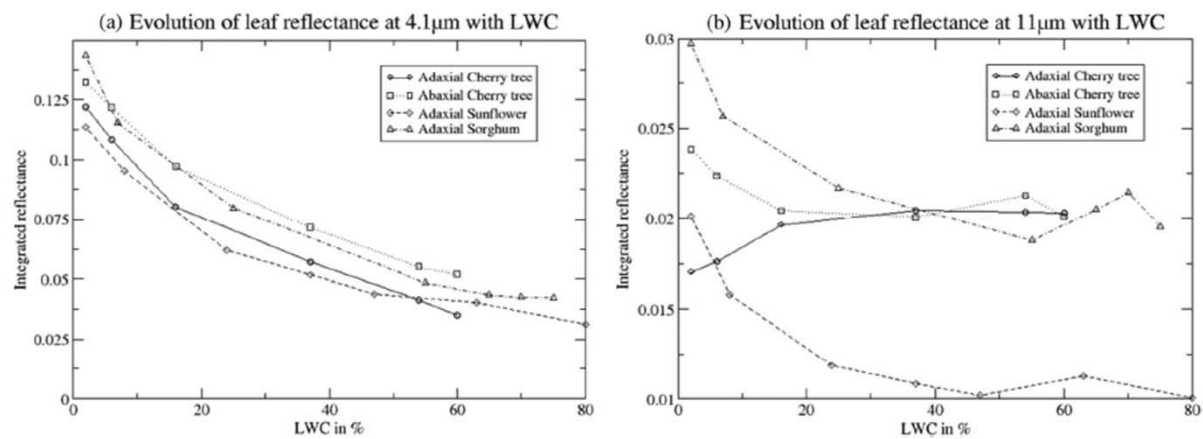


Fig. 3. Leaf reflectances at (a) 4.1 and (b) 11 μm as a function of LWC (wavelengths chosen in atmospheric window only).

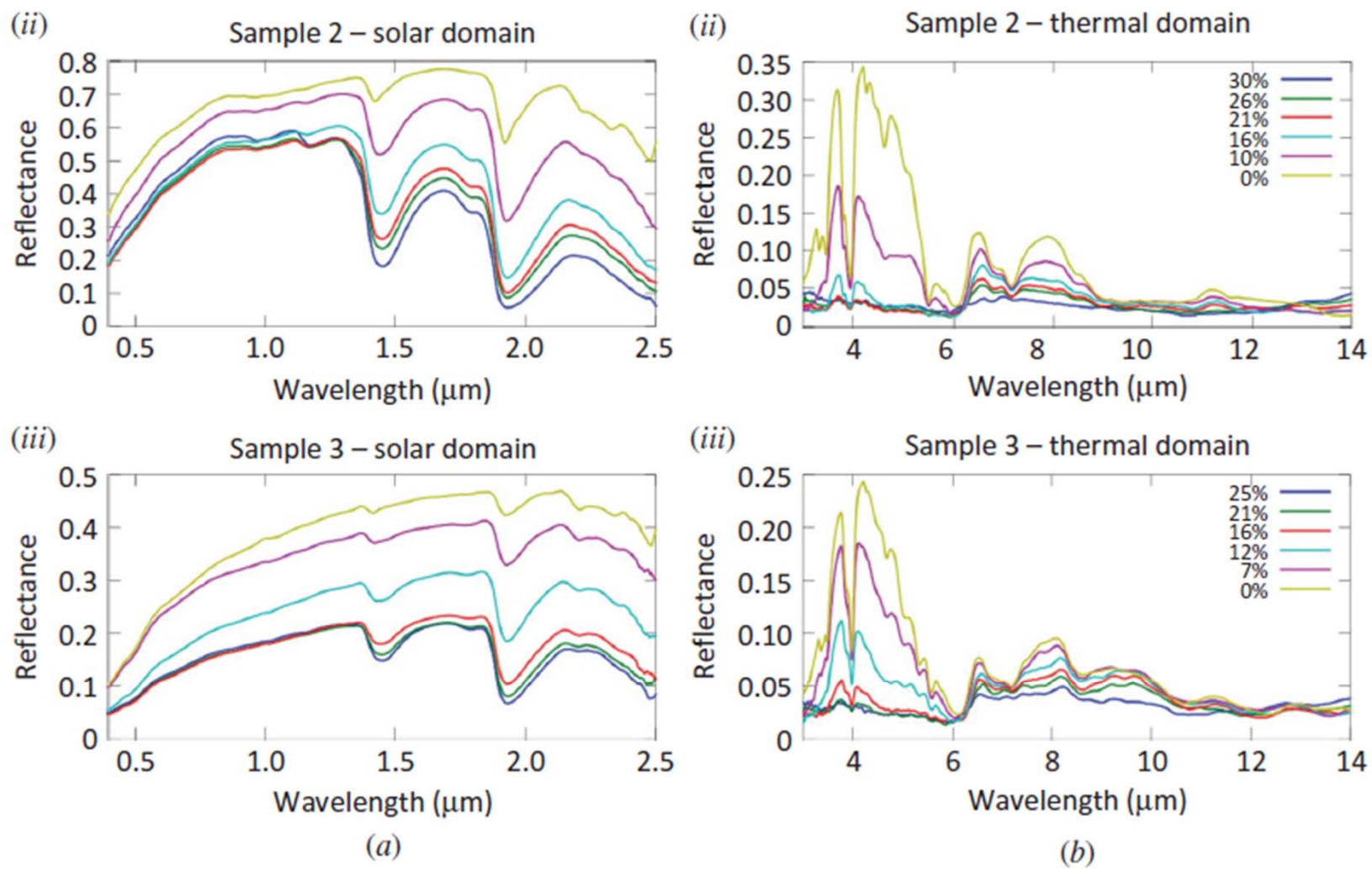


Figure 3. Spectral signatures of three soil samples (the so-called samples 1, 2, and 3) depending on SMC (values in %), in the solar (a) and the thermal (b) domains.